SCIENCE:
A NEW OUTLINE

By J. W. N. SULLIVAN

AN ATTEMPT AT LIFE
ASPECTS OF SCIENCE—FIRST SERIES
ASPECTS OF SCIENCE—SECOND SERIES
THREE MEN DISCUSS RELATIVITY
BUT FOR THE GRACE OF GOD
A HISTORY OF MATHEMATICS
THE BASES OF MODERN SCIENCE
BEETHOVEN
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Illustrated

THOMAS NELSON & SONS LTD
LONDON EDINBURGH
PARIS TORONTO NEW YORK

THOMAS NELSON AND SONS, LTD.
London :
35–36 Paternoster Row, E.C.4
Edinburgh :
Parkside Works, Dalkeith Road
Paris :
25 rue Denfert-Rochereau
Toronto :
91–93 Wellington Street West
New York :
381–385 Fourth Avenue

H. 52

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ILLUSTRATIONS

The drawings are by L. R. Brightwell.

INTRODUCTORY NOTE

IN this book we occasionally have to mention very large numbers. It would be wearisome, and rather confusing, to have to write such numbers out. We therefore make use of a certain very simple notation which is universally adopted by scientific men. This notation may be explained as follows: the figure 1 followed by six noughts is written 10^6. If 1 is followed by ten noughts it is written 10^{10}; if by seventy noughts it is written 10^{70}. These examples suffice to show us the general rule. It does not matter what the number of noughts is, the same rule applies. Besides very large numbers we have to deal with very small numbers. In this case we put a minus sign in front of the figure expressing the number of noughts. For instance, the number one million $= 1{,}000{,}000 = 10^6$. But one-millionth $= \frac{1}{1000000} = 10^{-6}$. We see that $10^{-6} = \frac{1}{10^6}$. This shows us the general rule.

This notation has the advantage of simplicity. It also has the advantage of clarity. The word billion, for instance, has a different meaning in America from its meaning in England. In England

it means one million million. In America it means one thousand million. This is confusing. But if, instead of using the word billion, the Englishman writes 10^{12} and the American writes 10^{9}, no confusion is possible.

The multiplication of large numbers of this kind is effected very simply by adding the "index" figures together. Suppose, for example, we wish to multiply one hundred thousand by one million, and then multiply the product by an English billion. One hundred thousand $= 10^{5}$. One million $= 10^{6}$. One English billion $= 10^{12}$. To get the product of these we add the index figures together, that is, $5 + 6 + 12 = 23$. Our answer, therefore, is 10^{23}. The same rule holds good for the very small numbers. A thousandth of a millionth, for example, is $10^{-3} \times 10^{-6}$. The result is 10^{-9}.

In all scientific discussions the units of measurement are the centimetre, the gramme, and the second. These units belong to what is called the centimetre-gramme-second system, often abbreviated as the C.G.S. system.

It may be of advantage to the reader to compare these units with familiar English standards. It takes rather more than two and a half centimetres to make up one inch. More precisely, we have 2.54 centimetres to one inch. A gramme is defined as the weight of a cubic centimetre of distilled water at a

temperature of 4° Centigrade (which is the temperature at which water is at its maximum density). This is equivalent to 15.443 grains, a small fraction of an ounce. The unit of time, the second, is, of course, the same as the unit we employ in ordinary time measurements.

Other units are built up, in the C.G.S. system, on the basis of these fundamental units. Thus the unit of force, called the *dyne*, is defined in the following way. A force is measured by the amount of motion it imparts to a given mass in a given time. A force which, operating for a second, gives one gramme a velocity of one centimetre per second, is called a dyne. The unit of energy, the *erg*, is the amount of work done by a force of one dyne in moving over a distance of one centimetre.

There are other units—electric, magnetic, and so on, which have been built up on the C.G.S. system, but for the purposes of this book it is not necessary to describe them.

As another specimen of where the international language of science differs from that commonly used in this country, we may instance the Centigrade and Fahrenheit scales of temperature. The Centigrade scale proceeds on the simple idea that the freezing-point of water shall be taken as 0 degrees, and its boiling-point as 100 degrees. The Fahrenheit scale calls the freezing-point of water 32 degrees, and its

boiling-point 212 degrees. These apparently arbitrary figures were not chosen at random. But the reasons that led to their selection are no longer valid, and there is nothing to recommend this scale but its familiarity. Needless to say, all scientific men use the Centigrade scale. The transition from one to the other is quite simple. Water, in passing from freezing-point to boiling-point, ranges from 32° to 212° on the Fahrenheit scale, that is, it ranges through 180 degrees. On the Centigrade scale it ranges through 100 degrees. This is the proportion of 9 to 5. For every nine degrees Fahrenheit we have five degrees Centigrade. Let us take a temperature at random. What is 240° F. on the Centigrade scale? We first deduct 32° to find out how many degrees above the freezing-point of water this temperature is. The result is 208° F. And every nine of these degrees corresponds to five Centigrade degrees. So we divide 208 by 9 and multiply the result by 5. Thus $\frac{208}{9} \times 5 = 115\frac{5}{9}$.

BOOK I

SECTION I.—THE EARTH

SCIENCE
A NEW OUTLINE

THE EARTH

§ 1. Its Dimensions

Measured by our ordinary standards the surface of the earth appears to be highly irregular. It is impossible to travel for more than a comparatively few miles in any part of such a country as England without finding hills and hollows succeeding one another. The flattest part of the earth is the surface of the ocean, and even that, as sea voyagers know, is by no means perfectly flat. On the other hand, we have the great mountain ranges—the Alps and the Himalayas—where the surface of the earth, broken and distorted, towers for miles into the air. Then there are the great ocean deeps, descending to miles below sea-level. Yet all these diversities, which bulk so large by ordinary human standards, shrink into utter insignificance when compared to the dimensions of the earth itself. Even if we take the

difference between the highest mountain peaks and the lowest ocean depths, the variation is still insignificant compared with the total dimensions of the earth.

If we represent the earth by a globe eighteen inches in diameter, then the height of the highest mountain above sea-level, on this scale, is only one seventy-fifth of an inch. A coat of paint applied to such a globe would fill up the deepest under-sea depressions and cover the highest mountain-tops. The wooden balls used by Americans in their bowling alleys are less round and smooth than is the earth.

Yet the earth is not a perfect sphere. It is flattened at the poles. The diameter of the earth, measured from pole to pole, is, fairly accurately, 7,899.98 miles, while its diameter through two opposite points on the Equator is 7,926.68 miles, a difference of 26.70 miles. This difference, on the scale of our eighteen-inch globe, amounts to one-sixteenth of an inch.

Of the vast bulk of the great globe of the earth we know nothing by direct observations. The deepest borings man has made have penetrated to a depth of less than one mile and a half. Thus any knowledge that science professes to have of the interior of the earth is based on indirect evidence. But such evidence can be, of course, extremely convincing. Nearly all our beliefs rest on such evidence.

The total mass of the earth is six thousand six hundred million million million tons, or, expressed more compactly, is 6.6×10^{21} tons. We can deduce from this that the interior of the earth must be much denser than its surface layers. For if we compare the weight of the earth with the weight of an equal globe of water we find that the density of the earth is more than five and a half times that of water. To be more precise, the density of the earth is 5.52 times that of water. But the density of the surface layers of the earth, compared with water, is only 2.7. It follows that the interior of the earth must be much denser, in order to bring the average density up to 5.52. We conclude that the earth increases in density as we approach its centre. It is estimated that, in the central regions of the earth, the density may rise to as much as ten times that of water. Besides increasing density we probably have also increasing temperature as we approach the centre of the earth. So far as borings go we find that the earth's temperature increases about 1° Centigrade for every hundred feet of depth. But there is still considerable difference of opinion respecting the precise constitution of the interior of the earth.

§ 2. Its Constitution

The surface of the earth obviously comprises three main divisions—the atmosphere, the sea, and the solid land. Each of these regions has a complex constitution. The atmosphere is composed of a mixture of gases, of which the chief are nitrogen and oxygen. More than three-quarters of the atmosphere is nitrogen, its precise proportion by weight being 75·45. Next to this comes oxygen, with a percentage by weight of 23·21. The rest of the atmosphere is composed of the following constituents: carbon dioxide, argon, hydrogen, water, neon, krypton, helium, xenon. The total mass of the atmosphere is less than a millionth of the mass of the solid earth. Nevertheless, the mass of the atmosphere, expressed in figures, is impressive. It is five thousand one hundred million million tons. Even xenon, the rarest constituent of the atmosphere, has a total weight of one thousand two hundred million tons.

No definite limit can be assigned to the height of the atmosphere. It becomes more rare as we ascend, but traces of some of its constituents could

probably be found at a height of several hundreds of miles. Direct observations on the air are confined to within a few miles of the earth's surface. Mountains make it possible to explore the air to a height of about four miles. Aeroplanes have ascended seven miles, and men in specially constructed balloons have reached a height of about twelve miles. No man has yet reached a greater height, but balloons carrying self-registering instruments have been sent up to a height of twenty-two miles. Our knowledge of the condition of the atmosphere above this height is inferred from various phenomena. Thus the observed duration of twilight shows that the air is sufficiently dense, up to a height of forty-five miles, to reflect a considerable portion of sunlight. For twilight is caused by the bending action of the air on the sun's rays, so that we still receive light from the sun after the sun has set. Meteors, or "shooting stars," give us information about still greater heights. Meteors are bits of stone, or metal, which rush into the atmosphere from outer space. Their speed is so great that the friction of the air raises them to incandescence, and we see them as brilliant streaks in the sky. We are often able to estimate their heights, and we thus find that there is evidence of the existence of air at heights exceeding one hundred miles. Further, the aurora borealis gives evidence

of the existence of air up to a height of five hundred miles.

But the great bulk of the air lies within a comparatively short distance of the earth's surface. No less than ninety-nine per cent. of the total mass of air is contained in a shell round the earth only eighteen and a half miles thick. Up to this height the atmosphere is the familiar air we breathe, composed chiefly of nitrogen and oxygen. At greater heights the constitution of the air becomes altogether different. Thus at something over sixty miles the atmosphere is almost entirely composed of hydrogen. The nitrogen content becomes a mere fraction of one per cent. while oxygen seems to disappear completely.

All gases, as we shall see in more detail later, are composed of tiny particles called molecules, flying about in all directions. The atmosphere is composed of a mixture of gases. Then why does not the atmosphere stream off into outer space ? What keeps it attracted to the earth ? The reason is that the molecules of the atmosphere are not moving sufficiently fast for them to be able to escape from the earth's gravitational attraction. We can illustrate the idea involved by considering what happens when a ball is flung into the air. We know that the ball, after reaching a certain height, starts to descend. But the greater the speed with which it

is projected upwards the higher it will rise. If its original speed were sufficiently great it would never fall, for the earth's gravitation would be unable to prevail against it. This critical speed can be calculated. It is seven miles per second. But even if a molecule of air was moving outwards with this speed it would not necessarily escape. It would depend on whether it had a free path or not. Near the surface of the earth a molecule of air experiences numberless collisions with other molecules every second, so that its path is continually being changed. At great heights, however, where the air is much rarer, the molecules stand a much better chance. Even then, the rate of leakage is very low. Calculation shows that there cannot be any appreciable leak of the atmosphere even in many millions of years.

On smaller bodies possessing a smaller gravitational attraction than the earth, the speed of escape is not so high. For the moon, for example, the velocity of escape would be only about one and a half miles per second. It is probably for this reason that the moon now possesses no atmosphere.

The third great constituent of the earth is the sea, for the amount of water contained in rivers, lakes, etc., is utterly insignificant compared with the volume of the ocean. The total volume of the ocean is 302 million cubic miles, and this is so distributed over the earth that the average depth

of the sea is $2\frac{1}{2}$ miles. If the water of the ocean were uniformly distributed over the earth, leaving no continents, it would still have an average depth of $1\frac{1}{2}$ miles. Sea water, as we know, is by no means pure water. It has many substances dissolved in it. If all the solids dissolved in the sea could be extracted they would form a compact block of nearly five million cubic miles. Spread uniformly over the earth they would encrust the whole earth to a depth of 112 feet. Of the six or seven different kinds of solid substances dissolved in the ocean the most prominent is common salt, which forms more than 75 per cent. of the whole. Besides these solid substances, various gases exist in solution in sea water. The most prominent of these is the gas, irrespirable by human beings, known as carbon dioxide. Even if we could breathe in water, as fishes do, we could not maintain life on the small amount of oxygen it contains, and even if the oxygen were made up to the required amount, the superabundance of carbon dioxide would suffocate us.

The weight of the ocean is immense compared with the weight of the atmosphere, but, immense as it is, it is less than $\frac{1}{4300}$ of the total mass of the earth. This mass is constantly but very slowly growing. Meteorites are continually impinging on the earth from outer space, and it is calculated that the accession of material so received amounts to 20,000 tons

per annum. But this is, comparatively speaking, an exceedingly small amount. If the surface of the earth accumulated material at this rate for a thousand million years it would only amount to a layer one inch thick. Thus both the rate of loss to outer space from the atmosphere and the rate of accumulation from outer space are so minute that we may say, with considerable accuracy, that the mass of the earth remains constant.

Such are the main outlines of this globe on which we dwell. For our direct experience we are confined almost wholly to its surface. Men have penetrated a few miles above its surface, and, for a much shorter distance, into its interior. On the scale of our eighteen-inch globe man's explorations would be covered by the thickness of a coat of paint. Nevertheless, although man's bodily movements are so restricted, his mental range is almost illimitable. The scientific survey which is possible to-day extends to countless millions of years before the first man appeared, and to countless millions of miles beyond the confines of his planet.

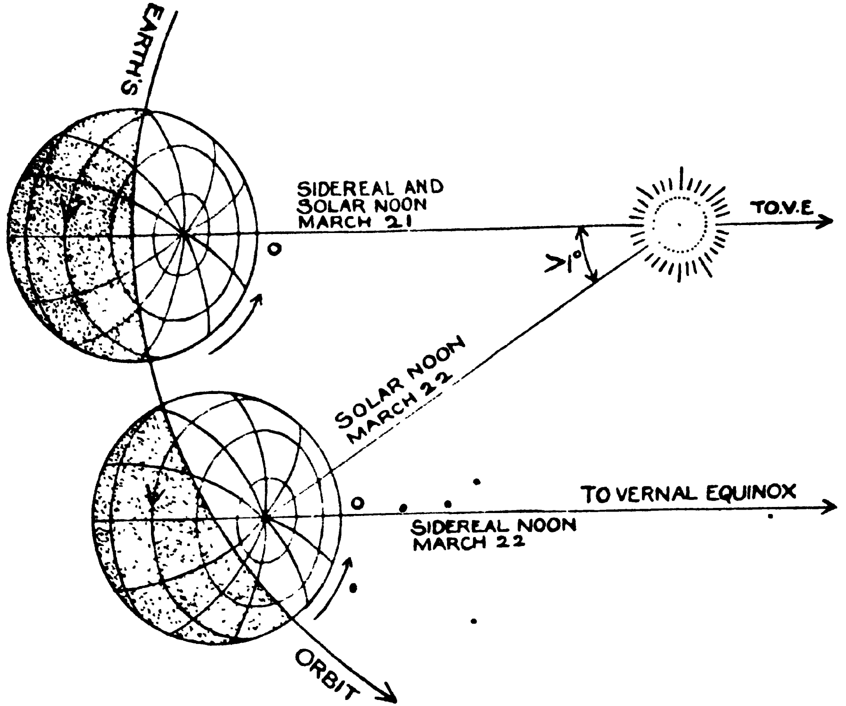
§ 3. Its Motions

The earth, as we know, floats unsupported in space. The earliest theories about the earth supposed that the earth was supported, and a variety of fantastic supports were imagined for this purpose. The childishness of these theories is shown by the fact that the supports do not form an unending series. These theories would suppose, for instance, that the earth is supported by a giant elephant, and this in turn by a giant tortoise, and this by something else. The series would end then. Apparently the primitive mind became fatigued after three or four repetitions of the question: "And what supports that?" The series idea is only intelligent if it goes on for ever.

The notion that any support at all is required comes, of course, from regarding "up" and "down" as unalterable directions in space. When it was realized that the earth is a sphere, the notions of up and down acquired a different significance. The "up" of the people in Australia is in the same direction as the "down" of people in England. And to people half-way between England and

Australia up and down are in directions that people in England would regard as side-ways. The fact is, of course, that " down " is the direction towards the centre of the earth, so that there is a different direction of down, and, consequently, a different direction for up, corresponding to every different point on the surface of the earth. Bodies fall down because they are attracted by the earth, and this attraction is always towards the centre of the earth.

The earth, floating in space, has two main motions. It rotates on its axis like a spinning top, and it also performs an almost circular journey round the sun. It completes one revolution on its axis every twenty-four hours, and it completes one journey round the sun in a year. As a matter of fact these statements are not quite accurate. Twenty-four hours is the time required for a spot on the earth to take up the same position with respect to the sun. But owing to the fact that the earth is moving round the sun this is a little longer than the time required for the earth to complete one revolution on its axis. (See diagram.) The difference is about four minutes. The year, also, can be reckoned in more than one way, according to the point in the heavens we take as fixed. But we need not go into these refinements here. Amongst the motions of the earth, however, we must refer to the conical motion of the earth's axis, the motion called pre-

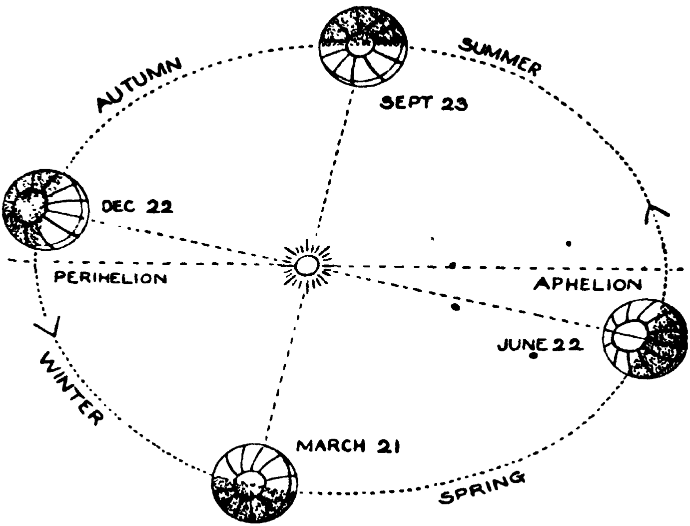


Influence of the earth's revolution round the sun on the length of the day.

cession. We know that if a spinning top is not absolutely vertical we have a sort of wobbling motion besides its motion of rotation. Its axis is describing a conical motion superimposed, as it were, on the motion of rotation of the top. The same thing happens with the earth. We can picture the state of affairs if we imagine the earth and the sun to be floating half submerged in some great ocean. We should then see that the earth's axis is not vertical, but is quite noticeably inclined. It is inclined at an angle of 23½ degrees. This axis is executing a conical motion, just like the axis of a wobbling top. It completes one revolution in 26,000 years. At present it is pointing close to the star Polaris, the pole star. People living in the year 7500 A.D. will find it pointing towards the star Alpha Cephei, which is quite some distance away. And even this motion is not a straightforward circular motion, but a wavy one. The earth has, in fact, quite a number of motions, and their full discussion would be very complicated.

The inclination of the earth's axis is the cause of the seasons. Each of the earth's poles, and the regions about them, lean towards the sun for part of the year, and, as the axis remains fixed in its direction in space, lean away from it for the rest of the year. (See diagram.) This has a double effect. During the summer the sun's rays pour down more vertically, and so are more concentrated than when

they come obliquely, and also these regions are in the sunlight for a longer time. Thus, on both counts, the heating effect of the sun is greater. In the northern hemisphere the greatest amount of heat



Showing how the earth's inclination on its axis produces the seasons.

is received from the sun about the 22nd of June, and the least about the 22nd of December. In actual practice, however, we find that the hottest days usually occur early in August, and the coldest early in February. This is because of the blanketing effect

of the atmosphere. The atmosphere prevents the rapid dissipation of heat, and so there is a storing-up effect. The heat accumulates day after day, for the out-goings, hindered by the atmosphere, are less than the in-comings. For the same reason the warmest part of the day comes, not at noon, when the sun is directly overhead, but some time after noon. The southern hemisphere, of course, is leaning away from the sun when the northern hemisphere is leaning towards it, and so it is summer in one region when it is winter in the other. At the Equator there is little variation between summer and winter, and little variation in the length of the day, because the inclination of the earth's axis naturally has little effect on that region.

§ 4. Its Origin

All the facts that we have hitherto given about the earth—its dimensions, its constitution, and its motions, are facts of the present day, so to speak. They are descriptions of what the earth is like now. But what is the history of this great globe? How did it come into existence?

The answer to this question must, of course, be to some extent speculative. Everything that we can observe exists in the present, and we have to deduce the past history of the earth from present observations. A study of the earth itself, or rather of that part of its crust which is accessible to us, carries us back a good way, but it does not enable us to answer the question as to the earth's actual origin. We have to take into account other bodies besides the earth. We have to take into account, for example, the other planets and the sun and the stars. All these objects play a part in enabling us to arrive at a conclusion respecting the earth's origin. In order to study this question it is not sufficient to consider the earth in complete isolation.

The earth is one of a number of planets revolving

round the sun, and the resemblances between them are so marked that we can justly regard them as a family. We suspect that they all came into existence in very much the same way, and that they all had a common parentage. Thus an explanation of the origin of the earth, if it is to satisfy us, must account for the origin of the other planets as well. The only absolutely unique thing about the earth, considered as one of the family of planets, is the fact that we live on it. Otherwise it is a not particularly distinguished member of the family of planets.

The resemblances amongst the planets may be tabulated as follows: they all move in nearly circular orbits round the sun. They all move in about the same plane about the sun, that is to say, if we imagine the sun and earth to be floating in an ocean, the other planets would also be floating in this ocean, or not very far from its surface. All the planets revolve in the same direction round the sun. All the planets revolve in the same direction round their axes.

Now these similarities are very remarkable, and cannot possibly be due to chance. The odds against it can be calculated, and are simply overwhelming. We must look for a common cause of all these resemblances. Before going into that question, however, it will be advisable to give a simple picture of this family of planets.

Let us represent the sun by a globe, 2 feet in diameter, placed in the centre of a level field. Then the nearest planet, Mercury, will be, to scale, a pin's head at a distance of 28 yards. The next planet, Venus, is a pea, and its distance is 52 yards. Then we come to the Earth, a slightly larger pea, distance 72 yards. The next planet, going outwards from the sun, is Mars, which would be represented by a large pin's head at a distance of 110 yards. The giant planet Jupiter comes next, a medium-sized orange at a distance of 390 yards. Then Saturn, a small orange at a distance of 690 yards. Four-fifths of a mile from the sun comes Uranus, a small plum. We then have Neptune, a large plum, at a distance of 1⅕ miles. Until two or three years ago it was thought that Neptune represented the limit of the solar system, but recently a still farther planet has been discovered, called Pluto. This is a small planet, and on our scale would be more than 1½ miles from the globe representing the sun.

One curious fact, brought out by this model, has a special significance. We see that, roughly speaking, the planets get larger as we go out from the sun until we reach Jupiter, and then, as we go farther out, they tail off again. We shall see that this fact provides a useful clue to our problem of the origin of the earth.

The great German philosopher, Immanuel Kant,

was the first to put forward a theory of the origin of the solar system that has become famous. This is the so-called Nebular Hypothesis. In the form in which Kant left it the theory might not have attracted much attention, but it was developed by the very great French mathematician, Laplace, and so attracted the serious attention of the scientific world. This theory supposes that the whole solar system was originally one great mass of glowing gas. The gas was supposed to be rotating. Such a mass of gas would contract under the mutual gravitational attraction of its particles, and, when the attraction had gone a certain way, an outer ring of gas would be separated off from the main body. Further contraction would separate off a second ring, and then a third ring, and so on. The theory then supposes that each of these rings condensed into a compact mass. Each of these masses became a planet. The central mass which was left after all the rings had been thrown off condensed to form the sun. This theory explains a good many things about the solar system, and it enjoyed a great reputation and popularity for many years.

Unfortunately, when the mathematics of this theory is gone into more thoroughly, it is found to be quite impossible. The scale is too small. Rings thrown off in the way supposed would not condense to form planets, but would dissipate themselves

throughout space. The rings would have to be very much larger in order that the mutual gravitational attraction of their parts should be sufficient to hold them together. The formation of bodies as small as the planets cannot be explained in this way. Hence this theory, very popular in the nineteenth century, has now been given up.

The most promising theory that we have to-day is the so-called tidal theory. It is not yet perfect, but it explains a good many things. This theory attributes the formation of the solar system to an accident. We are to suppose that, some thousands of millions of years ago, a wandering star passed close by the sun. The effect of such a close approach would be to raise enormous tides on the sun. Indeed, if the approach were close enough, a huge filament of matter would be torn out of the sun. This filament, it can be calculated, would be a cigar-shaped structure. At various points along it condensations would occur, these condensations being most massive where the cigar was thickest, that is, about the middle. Gradually these condensations would form distinct masses, and the cigar-shaped filament would be replaced by a number of separate bodies. Thus the planets would be born.

For some little time after their birth the planets would be describing highly complicated orbits, since

they would be acted on by the gravitational attraction of both the sun and the passing star. As the disturbing star receded, however, its influence would, of course, grow less, and the orbits of the planets would become more regular. Nevertheless, the orbits would still be very different from the almost circular orbits that the planets now move in. But we may very reasonably suppose that the original disruption left a great deal of matter, in the form of dust or gas, scattered about in the neighbourhood of the sun. The planets, in moving through this dust, would encounter a resistance to their motion. The effect of this resistance, as can be shown by mathematical reasoning, would be to make the planetary orbits more circular. In fact, if the resistance were continued long enough it would make the planetary orbits absolutely circular. But the planets would be gradually sweeping up this dusty matter as they moved through it, and we must suppose that its resistance became negligible before the orbits of the planets had time to become absolutely circular.

There is no need to pursue this theory into greater detail since we are here concerned only with the origin of the earth. We may mention, however, that the theory accounts in quite considerable detail for the diverse phenomena of the solar system. The reader will have noticed already that it accounts,

roughly, for the variations in size of the planets, since the condensations occurring in a cigar-shaped filament would give just that diversity. The fact that the correspondence is not exact, that Mars, for instance, though farther from the sun, is smaller than the earth, can also be accounted for by the theory when that is pursued into detail.

Supposing, then, that the earth originated as a mass of glowing gas torn from the sun, what has been its subsequent history? Calculation shows that the earth, from being a mass of gas, must have cooled sufficiently to assume the liquid form within 5,000 years. It may have taken much less time than this, but certainly the earth was completely liquid within 5,000 years of its formation. From being a liquid the earth cooled to the solid state. This process would take longer, but it is not likely to have taken longer than 10,000 years. Thus we may say that the earth was mainly solid within 15,000 years of its formation. This is an exceedingly small fraction of the total age of the earth, for it is practically certain that the earth is more than a thousand million years old.

One way of deducing the age of the earth is from consideration of the shape of the planetary orbits. We have said that these orbits are very nearly circular, whereas, at the time the planets were formed, they were very far from being circular. We have also

said that the change was due to the resistance of the dust that was scattered about in space. The length of time that would be required for this change to take place can be calculated. The calculation is very rough, but it gives the conclusion that the age of the earth is probably not less than one thousand million years, nor more than ten thousand million years.

The discovery of radium has made another line of argument possible. We know that radium is a substance whose atoms are breaking up. We shall see later that atoms are not simple bodies, but consist of parts. A radium atom shoots out part of itself and thus changes into the atom of another substance. Now radium is not the only substance that splits up in this way, although it is the most active. Amongst the " radio-active " substances, as they are called, is uranium. This substance passes through a whole series of changes, transforming itself into different substances, and finally settles down as lead. In any sample of uranium a certain proportion of it is changing itself into lead. The rate at which this process goes on is quite invariable. Nothing that we can do to the uranium—no extremes of temperature or pressure—affects its rate of disintegration in the slightest. This rate of break-up is known. In a sample of uranium one atom in every seven thousand million breaks up every year.

Now the lead that comes from uranium is not quite the same as ordinary lead. If we find both lead and uranium present in a mineral we can find out if the lead has come from the uranium. And from the proportion of the lead to the uranium we can say what time must have elapsed to produce that percentage of lead. It has thus been found that the age of some rocks is about fourteen hundred million years. And from the formation of these rocks we know that the matter in which they are embedded must be still older. A good round figure for the age of the earth is two thousand million years. Even double this figure is possible.

SECTION II.—GRAVITATION

GRAVITATION

§ 1. The Law of Gravitation

Gravitation is the most universal of the forces of nature. It has also been generally regarded as the most mysterious. Every particle of matter in the universe exerts a force of attraction on every other particle. The moon remains circling round the earth instead of flying off into space because the moon and earth attract one another. Similarly, the earth continues its yearly journey round the sun because of the mutual attraction between the earth and the sun. Similarly for the other planets. And this mutual attraction that bits of matter have for one another is not confined to the solar system. It extends throughout the whole universe. Far in the depths of space we can see systems of stars circling round one another, and from a study of their motions we can calculate that they obey the same law of gravitation that is obeyed here on earth.

There is no limit to the distance to which the force of gravitation extends. The influence of the earth, for example, reaches to the most distant star. Whenever we crook a finger all the hosts of heaven are affected.

The actual law according to which this force varies was first given by Sir Isaac Newton. He found, as we should expect, that more massive bodies attract one another more strongly than do less massive bodies. In fact, the attraction is proportional to the mass; that is to say, if we double the mass we double the attractive force; if we increase the mass three times we increase the force three times, and so on. Newton also found that the force between two masses gets less the farther the masses are away from one another. This also we should expect, but the force does not decrease in a simple proportion. It falls off much more rapidly than that. If the distance is doubled, for instance, the force is not simply halved, it is reduced to a quarter of what it was before. If the distance is threefold what it was the force is one-ninth of what it was. Four times the distance gives a sixteenth of the force. And so on. This law is expressed by saying that the force varies inversely as the square of the distance. Thus although it is theoretically true to say that crooking a finger influences all the stars, it is a statement that, in any practical sense, may be utterly ignored.

The force of gravitation is unique amongst the forces of nature in its unalterability. By heating or cooling a body, for instance, we do not in the least affect its gravitational attraction. Nor does its gravitational attraction depend in any way upon its

chemical constitution. It depends only upon the mass of the body. An even more curious fact is that the medium through which the gravitational force passes is entirely without influence on it. Nothing acts as a screen to gravitation. We know substances that are opaque to light, and we know substances that are opaque to heat. A glass fire-screen, for example, will block a good deal of the heat of a fire, but will let most of its light through. And there are substances which will block off nearly all the light, but will let the heat through. The electric and magnetic energies can also be screened. Even X-rays will not penetrate everything. But the gravitational force that one body exerts on another is not affected at all by what lies between them. There is nothing we can do which will increase or diminish the gravitational attraction between two bodies, provided, of course, they remain at a fixed distance apart.

§ 2. Weighing the Earth

The weight of anything on the earth is due to the attraction of the earth on it. A pound weight is being pulled towards the earth with the force of one pound. We see this most easily if we weigh a body on a spring balance. The spring is stretched. *Obviously there is a force pulling* it downwards. If we took our pound weight and spring balance to some body less massive than the earth, say to the planet Mars, the spring would not be stretched so much. Judged by the reading of the spring balance our pound weight would weigh less than a pound. On a more massive body, such as Jupiter, it would weigh a great deal more than a pound. We should be able to say, from these experiments, how much more massive Jupiter is than the earth, and how much more massive the earth is than Mars.

This suggests to us an experiment that we can actually perform. We must remember that every piece of matter attracts every other piece of matter. Between ordinary pieces of matter, as, for instance, a couple of apples, this attraction is imperceptible. But a sufficiently large piece of matter, say, a moun-

tain, might exert an appreciable attraction. The first man to try out this idea was the Frenchman, Bougier, in 1740, who tried to measure the attraction of the great mountain, Chimborazo, in the Andes—a mountain 20,000 feet high. The method was to hang a plumb-line at the side of the mountain and to notice how far the mountain's attraction pulled the plumb-line out of the straight.

The principle of this experiment is, we see, very simple. The plumb-line is acted on by two forces. The earth is pulling at it in a downward direction, and the mountain is pulling at it sideways. The plumb-line will therefore take up some position between the vertical and the horizontal. The actual position it takes up will depend on the relative strengths of the two pulls. The pull exerted by the mountain is proportional to its mass, just as the pull downwards is proportional to the mass of the earth. By measuring the deflection of the plumb-line, therefore, we can find how much more massive the earth is than the mountain. If Bougier knew the mass of the mountain, therefore, he could, by this experiment, find the mass of the earth. (The fact that the mountain is, as it were, separated from the rest of the earth in this experiment makes so little difference that it is quite negligible.)

As a matter of fact Bougier did not obtain very accurate results on this occasion. This is not to be

wondered at, for the practical difficulties to be overcome were very great. Bougier made his experiments from two stations. The first was on the south slope of Chimborazo, just above the perpetual snow-line, and the second was nearly on the same level, several miles to the westward. His expedition took ten hours to clamber to the first station, a most toilsome journey over rocks and snow, and when they were there they had to fight continually against the snow, which threatened to bury their tent. They had to wait a few days before they were able to move on to the second station, and they then encountered conditions that were still worse. They encountered a terrific wind, which filled their eyes with sand, and was continually on the point of blowing away their tent. Also, the cold was intense, and they had to apply fire to the levelling screws of their instruments before they were able to turn them. These were scarcely ideal conditions in which to make delicate scientific observations, and Bougier himself did not attach very much value to his measurements. The figure he reached for the mass of the earth was undoubtedly too great; but, as he points out, his experiment had at least disproved the idea that the earth is a hollow shell, which some people had held, and it also proved that the earth is not a globe full of water, which others had maintained.

Thirty years later a similar experiment was con-

ducted in Britain, the mountain selected being Schiehallion, in Perthshire. The necessary observations took a long time, and were very carefully performed. The final result was to the effect that the earth weighs five times as much as an equal volume of water. The best attested modern figure gives 5.52 for the density of the earth, so we see that this early estimate was quite close to the correct result.

The great disadvantage of all such experiments, however, is that no really accurate estimates can be made of the great masses involved. The size and density of a mountain, for example, can only be roughly estimated. Much more accurate results can be obtained by experiments on much smaller bodies—on bodies small enough, in fact, to be handled in the laboratory. The first experiment of this kind was designed by the Rev. John Michell, who invented an apparatus sufficiently delicate to measure the attraction between spheres of lead a few inches in diameter. He did not live to perform the experiments, however, and they were not carried out until 1797, when Cavendish took the matter up. Since then a number of similar experiments have been performed, and we now know, pretty accurately, that the mass of the earth is 5.52 times that of an equal volume of water.

§ 3. Weight and Mass

In ordinary language, when we speak of the weight of anything, we mean its weight as measured on the surface of the earth. Every particle of the earth is pulling at the object whose weight we are measuring, and the resultant effect of all these pulls is what we call the weight of the object. These pulls are in very different directions. Only those particles which lie on a direct line from the object through the centre of the earth are pulling the object directly downwards. It is easy enough to see that all other particles are pulling the object partly downwards and partly sideways. Yet, as we know from experience, the sum total effect of all these pulls is directly downwards. An object we are weighing shows no tendency to move in any sideways direction. This is what we should expect on a spherical body like the earth, for we see that any sideways pull, say, to the east, is compensated by an equal sideways pull to the west.

Not all the particles of the earth pull at the object with equal force, for the strength of a particle's pull

depends on its distance from the object. If we are weighing an object in London it is obvious that a stone in Southend is pulling at it with a greater force than is an exactly similar stone in Timbuctoo. Taking into account the different directions and distances of all the particles of the earth, what would be their total effect? Sir Isaac Newton proved the beautiful theorem that the attraction of a spherical body on any object not inside it is the same as if the whole mass of the spherical body were concentrated at its centre. The effects of all these different pulls, varying in strength and direction, are summed up in that statement.

Consider, for example, the earth and the sun. Here we have two spherical bodies, and every particle of each of them is pulling at every particle of the other. But to calculate the total effect we can imagine the whole mass of the sun concentrated at a point at its centre, and the whole mass of the earth concentrated at a point at its centre. So that if we know the masses of the sun and of the earth we require to know, in addition, only the distance between their centres. The whole complicated business of estimating separately the pulls of every pair of particles is thus avoided by this simple formula.

The total pull of the earth on an object we are weighing is the same as if the whole earth were

concentrated at its centre. Therefore the earth's pull on an object is always towards the centre of the earth. For an object on the surface of the earth this centre is distant about four thousand miles. An object at some height above the surface would be at a greater distance from the centre, and therefore the earth's pull would be less, that is to say, the object would weigh less. At a sufficiently great distance from the earth, far in outer space, the weight of the object would be altogether imperceptible.

Thus we see that the weight of anything is not an invariable quantity. We must distinguish between the *weight* of a body and the *mass* of a body. Newton defined the mass of a body as the quantity of matter in it. This obviously remains the same whether we suppose the body to be on the surface of the earth or far out in inter-stellar space. It is not dependent on the position of the body with respect to other bodies. The weights of two bodies will be proportional to their masses if we are weighing them at the same place, and for this reason we often take weight as being equivalent to mass. We buy butter by the pound, for instance, because the weight is a correct indication of the quantity of butter we are getting. On the planet Jupiter the same quantity would weigh a great deal more. A man on Jupiter (supposing that were possible) would find a meal of a half-pound of steak extremely un-

satisfying. It is not really the weight but the quantity, or mass, that he is interested in.

Since the weight of a body varies with circumstances, while its mass remains invariable, it follows that we must have some means of determining the mass of a body other than weighing it. If we apply force to a body, as by pulling or pushing it, then, if the body is free to move, we generate motion in it. The greater the mass of the body the less is the motion we generate, provided, of course, that we are using the same degree of force for the same length of time. This fact enables us to measure mass. Wherever this experiment was performed, whether at the surface of the earth or far out in space, the result would be the same. The same force would always produce the same amount of motion in the same mass, provided it acted for the same length of time. If we double the mass we halve the motion generated. And so on.

The masses of bodies can also be estimated by collisions. A body in motion requires a certain force to stop it. The more massive the body, provided the speed is the same, the greater the force required.

Now all these experiments for determining mass seem to be entirely independent of gravitation. The masses of two bodies could be determined by collision experiments without paying any attention at

all to the attraction they have for one another. In fact, if the reader will think carefully about what we have already said, he will see that the word "mass" seems to refer to two different qualities of a body. For we have already said that the gravitational attraction between two bodies is proportional to their masses. By measuring their attractions, therefore, we could deduce their masses. We have also said that we can deduce their masses by letting them collide with one another. Are the masses referred to in these two experiments the same? We can see no a priori reason to suppose that they are the same, and, as a matter of fact, they have received two different names, namely, gravitational mass and inertial mass. Nevertheless, the most precise experiments fail to reveal any difference between them. If the collision experiment reveals that one body has twice the inertial mass of another, then the attraction experiment will reveal that it has twice the attractive force. This strict correspondence is absolutely invariable, and seems to be, when one thinks about it, very mysterious. For it seems quite easy to imagine that matter might have existed without possessing gravitative force. If we met a stone in outer space and hit it with a stick it would move, and its speed would depend on the force of the blow and on its inertial mass. But why should the stone have this mysterious power of attracting

all other stones—indeed, all matter ? Yet we never have the one without the other. Can it be that gravitation and inertia are two names for the same thing ? This is a question that very few men of science seem to have worried about. But one man not only worried about it profoundly, but solved it ; and the result is that great revolution in science known as Einstein's Theory of Relativity.

§ 4. LAWS OF MOTION

MOTION, in the minds of most people, is really quite a vague idea. We have countless examples of all kinds of motions going on around us every day, but few people discriminate between them with any degree of precision. And the subject seems to be, to most people, uninteresting. Perhaps it is for that reason that mankind was so long in developing correct notions on motion. Although motion is one of the most familiar things in our experience, it is only about three hundred years ago that it began to be properly understood. Nevertheless, it is a subject which is, scientifically speaking, of immense importance. No real understanding of any branch of physical science can be obtained without some knowledge of the phenomena of motion.

The simplest form of motion is motion in a straight line with a uniform velocity. Neither the direction nor the speed of the body alters. Newton's first law of motion states that a body upon which no force acts must be either at rest, or else it must be moving in a straight line with uniform velocity. This statement is, at first sight, somewhat unex-

pected. We are not surprised at the first part of the statement. That a body at rest should remain at rest, unless it is interfered with, seems to us quite natural. But that it should persist indefinitely in motion, without anything to cause the motion, seems, at first sight, rather odd. Ordinary experience teaches us that a motion, once started, sooner or later comes to rest. But if we examine the matter, we find in every case that some force has been acting against the motion. If we bowl a ball along a level ground, for example, there is friction between the ball and the ground, and it is this friction that causes the final stoppage of the ball. The ball would go farther on a sheet of ice, for the friction would be less. Nevertheless there would always be some friction, so the ball would not go on for ever. The first law states that in the absence of all friction, and of any other interfering agent, such as the resistance of the air, the ball would go on for ever. And, when we think of it, we can see no reason why it should not. If the direction of the motion changed, or if it became faster or slower, we would naturally ask why ? Provided there is no interference the body will keep on as it is.

This natural persistence of a body in motion applies only, it must be noted, to motion in a straight line, and at a steady speed. Any alteration in direction requires explaining, just as an alteration

in speed requires explaining. A circular motion, for example, is not a natural motion. A body can only move in a circle if it is continually acted on by a force bending it out of its straight-line path. A stone whirled round at the end of a string, for example, is continually being pulled towards the centre of the circle by the string. If we release the string then, as we know, the stone simply flies off. The fact that the planets move round the sun instead of pursuing a straight-line path is sufficient to show that a force is acting on them—a pull from the sun, according to Newton's theory of gravitation. If we project a stone into the air it does not go on in a straight line for ever. That is because the earth's attraction bends it down to the earth again.

That quality of matter which makes it persist in its state of rest or of uniform motion in a straight line is called Inertia. Inertia is really an expression of the fact that matter is completely passive. Thus we may say that a piece of matter at rest remains at rest because it has no power of initiating any change. The same quality is shown by its persistence in straight-line motion with uniform velocity. Motion can change only in two ways, direction and speed. A piece of matter in motion, if left to itself, changes in neither of these respects owing to its complete passivity or inertia.

We have remarked that motion has two charac-

teristics—direction and speed. These two characteristics are indissolubly linked together. Any motion whatever must have a direction, and must have a speed. Force is another quantity with two characteristics. Force has direction, and it also has magnitude. We may point out, incidentally, that this is not true of all physical quantities. Temperature, for instance, has nothing corresponding to direction. It has magnitude, and that is all.

Now when force acts on a body which is free to move it generates motion in that body, and the direction of the motion it generates is in the direction of the force. And the amount of the motion it generates is proportional to the amount of the force. This is Newton's second law of motion. If more than one force is acting on a body at the same time, each force produces its effect quite independently of the others. The resultant motion of the body is compounded out of the motions that each of the forces would produce if it acted separately.

These remarks on motion may strike the reader as somewhat dull. Nevertheless, the elementary concepts of motion are necessary to any understanding of the phenomena dealt with by the science of physics. The more spectacular results that we shall deal with later will be found to be much easier to understand if we have clear ideas of three or four fundamental terms. Velocity is one of these terms,

and it is a term with which everybody is familiar. It may be defined as rate of change of position. It may be uniform or it may be varying. If it is varying we require a new term, namely, acceleration, to express the rate of change of a velocity. In these days of motor cars this term also is very familiar. We all know that the speed of a car is not the same thing as its acceleration, and that a car with exceptional acceleration is, for some purposes, to be preferred to a car with a higher maximum speed, but which works up to that speed at a slower rate. A falling stone has acceleration ; it does not fall at a uniform speed. We see also, by an obvious extension of ideas, that an acceleration may be uniform or varying. There is such a thing as the rate of change of an acceleration. And we could evidently continue with this idea indefinitely. But these refinements are not of sufficient importance to have received special names.

The notion of acceleration is a particularly important notion, for the acceleration of a body is a measure of the force acting on it, provided, of course, that the body is free to move. If such a body is *accelerating*, then we know that a force is acting on it ; if it is not accelerating, then no force is acting on it. It must be noted here, as a very important fact, that the effect of a force on a body does not in the least depend on the velocity that

the body already has. If we are throwing a ball to and fro on a steadily moving train or ship, for example, we have to make exactly the same effort as if the train or ship was at rest. If we were playing billiards we would have to use exactly the same degree of strength to make the same shots. Pendulums would swing at the same rate. A rifle bullet, fired from the middle of a steadily moving ship, takes as long to reach the bows as it does to reach the stern. In fact, provided our experiments take place within the moving system, there is no way of telling whether we are in motion or not. The effects produced by the forces we use are quite independent of our already existing velocity, whether that be great, small, or zero. Therefore, we can only say we are moving by reference to some outside standard. And the degree of motion we attribute to ourselves will depend on the standard we select. This is what is meant by the statement that motion is relative.

Let us suppose, for instance, that we are in a train moving at sixty miles per hour. What does that statement mean? Evidently it means that we are passing fixed objects outside, such as railway buffets, trees, telegraph posts, at the rate of sixty miles an hour. But these so-called fixed objects are all partaking in the motion of rotation of the earth on its axis. So that, with respect to the earth's

axis, our train is moving in quite a different way. But even the earth's axis is not fixed in space. The whole earth is moving round the sun. And the sun and the whole solar system is moving quite rapidly through space towards the star Vega. And Vega and the sun and the whole system of stars of which they form part is in motion with respect to other systems of stars, which are themselves moving with respect to one another. There is o absolutely fixed point from which we can measure our motions. Motion is relative.

SECTION III.—MATTER

MATTER

§ 1. Its Atomic Constitution

All matter possesses inertia, and is capable of motion, and from these facts alone a great deal that is of scientific interest has been discovered. It has been proposed to define matter as that which possesses these properties. Thus when scientific men were debating whether heat is " material " or not, they tried to decide the question by investigating whether heat possesses inertia. When the mathematicians showed that an electrically charged body required more force to move it—that is, possessed more inertia—than an uncharged body, electricity immediately became a more material thing than it had been. Light, also, became materialized, as it were, when it was discovered that it exerts pressure on any object on which it falls. Inertia, we may say, is the most fundamental property of matter.

But even if heat, light, and electricity have finally to be ranked as matter, it is nevertheless true that they differ very greatly from the matter of ordinary experience. In this section we shall confine the term matter to the matter investigated by the science of chemistry.

The most obvious fact about matter is its amazing diversity. Its three main divisions are solids, liquids, and gases, and within each of these three classes there is an immense variety of substances. Most of these substances, by one means or another, can be split up into simpler substances. Thus water is a compound of two substances. It can be split up into hydrogen and oxygen. Ordinary table salt can be split up into sodium and chlorine. A very long list of substances could be given that could be split up in this way. In fact, out of the hundreds of thousands of substances known there are only ninety-two which cannot be split up. These are what the chemists call elements, and all other substances are composed of two or more of them.

In a compound substance, that is, one composed of two or more elements, the elements composing it are always present in the same proportions. In no sample of the substance do we ever find a little more of one element or a little less of another. Consider, for example, the well-known substance called sal ammoniac. We can decompose this into ammonia gas and hydrochloric acid gas. Ammonia gas can in turn be decomposed into nitrogen and hydrogen. The hydrochloric gas can be decomposed into hydrogen and chlorine. The process cannot be carried any further. Nitrogen, hydrogen, and chlorine are elements. If we started with 100 ounces of sal

ammoniac we would have, at the end of the operation, 26.16 ounces of nitrogen, 7.50 ounces of hydrogen, and 66.34 ounces of chlorine. And any other sample of sal ammoniac would give us these constituents in precisely these proportions. This is an example of a general law which may be enunciated as *the same compound is always formed of the same elements in exactly the same proportions.*

But although the same elements always combine in the same proportions to produce the same compound, it is quite possible for those same elements to combine in different proportions to produce a different compound. For instance, three ounces of carbon will unite with eight ounces of oxygen to produce the substance called carbon dioxide. But we can also cause three ounces of carbon to unite with *four* ounces of oxygen to produce the quite different substance called carbon monoxide. It will be noticed that in the first case we have exactly twice the amount of oxygen we have in the second case. This is typical. For instance, we can form three distinct compounds of nitrogen and oxygen. These compounds are formed by combining respectively one, two, and four parts of oxygen with a given amount of nitrogen. These facts, and many others like them, were first satisfactorily explained by the atomic theory of matter.

The atomic theory asserts that a chemical ele-

ment is composed of ultimate, irreducible particles. These particles are called atoms. A compound is formed by the atoms of two or more elements uniting together. The ultimate particles of which a compound is composed, each particle consisting of a combination of two or more atoms, are called molecules. Now on this theory the numerical results we have given above receive a natural explanation. Let us take, for instance, the compounds formed by carbon and oxygen. One of these compounds has twice as much oxygen as the other. This is what we should expect if, in the first case, one atom of carbon unites with one atom of oxygen, and, in the second case, one atom of carbon unites with two atoms of oxygen. Writing in symbols, we represent the first case by CO, and the second by CO_2. A compound of carbon and oxygen must have in every molecule at least one atom of oxygen united with each atom of carbon, for less than an atom cannot take part in any chemical process. And for the same reason, if we are to have more than one atom of oxygen in the compound molecule, we must have at least two. So that the second compound must contain at least twice as much oxygen as the first. There might be compounds, of course, with three times as much oxygen, four times as much, and so on. But there could not be intermediate quantities if the atomic theory is correct. Thus the fact that no intermediate

chemical compounds have been found is a strong support of the atomic theory.

Before going on to describe other evidences for the atomic theory we must clear up one possible misunderstanding. When we say that the atom is an ultimate, irreducible particle, we are referring wholly to chemical methods of analysis. An atom is the smallest part of a substance that is known to take part in any chemical process. It was for a long time supposed to be a hard, homogeneous little particle. But we now know that it is a very complex body, built up of particles much smaller than itself. These particles are of the same kind in all atoms, however. Different atoms contain different numbers, differently arranged, of these little particles. And it is due to these different numbers and arrangements that we owe all the varieties of matter—*i.e.* of the chemical elements.

Thus it is still true that the smallest part of any definite substance is an atom.

The atomic theory explains an immense variety of facts. It is, indeed, one of the most successful of all scientific ideas. Let us consider a few of these facts.

If two liquids are taken, and one is placed on top of the other, we know that they will begin to mix. With most pairs of liquids we find that they are thoroughly well mixed in quite a short time. In

some cases the process takes longer. But, even if we take a very unfavourable case, such as ether and water, we find, after a time, that every layer of the ether contains some water, and every part of the water contains some ether. Ultimately the two liquids would become equally diffused throughout. In some cases this process takes a very long time. Thus let us suppose that we have a vertical glass tube a yard in length and that we fill the lower half with a strong solution of copper sulphate. On top of this very carefully pour clear water. After a time we shall see that some of the colour of the copper sulphate has spread through the top half of the tube, the colour of the lower half of the tube having become fainter. But the colour would not be uniform all through, that is, diffusion would not be complete, until considerably more than ten years had elapsed.

Even with solid bodies diffusion occurs. With pairs of metals that have been kept in contact for years it is found that the bottom layer of the one and the top layer of the other have become, to some extent, intermingled. The diffusion of mercury through lead has been shown by a very striking experiment. A bent piece of lead had one arm placed in mercury. After a time mercury was found trickling out of the other arm. In another experiment a layer of silver was deposited on copper. The

copper was heated and the silver disappeared. When the copper surface was etched away the silver was found underneath.

Gases, as we know, diffuse very rapidly. The French scientist, Berthollet, took a globe containing carbon dioxide, a heavy gas, and placed above it a globe containing hydrogen, the lightest of gases. The two globes were put in communication by a tube. After a little time it was found that each globe contained as much hydrogen as carbon dioxide. With any pair of gases the result is the same.

It is easily seen that we can explain these phenomena if we assume that matter is composed of small ultimate particles, and that these particles are in movement. In a solid the motions of the particles, the atoms or molecules, are relatively restricted. For that reason diffusion between two solids is a very gradual process. In a liquid the movements are freer, while the maximum of freedom is achieved by a gas. We shall discuss this matter of molecular movements in greater detail later.

Assuming that atoms exist, of what size are they ? A thin piece of gold-leaf has a thickness of one ten-thousandth of a millimetre. It is certain, therefore, that the diameter of an atom of gold is less than the thickness of one of these sheets, that is, is less than 10^{-5} cm. The weight of a cube of gold, having this length for the length of its side,

would be 10^{-14} gramme. But the gold atom may, of course, be very much smaller than this.

The study of thin films takes us a good deal further. In a soap bubble we often notice, besides the familiar brilliant colours, small round black spots with well-defined edges. These spots might be taken for holes, and their appearance is, indeed, followed by the bursting of the bubble. But these spots are not holes, for it can be shown that they reflect light. The thickness of these black spots can be measured, and they are found to have a thickness of 4.5×10^{-7} cms. Films produced by spreading oil drops on water may be even thinner. Films as thin as 10^{-7} cms. have been produced in this way. Now these oil molecules are relatively enormous things, being built up of a great number of atoms. A molecule of glycerine trioleate, for example, consists of 37 atoms of carbon, 104 atoms of hydrogen, and 6 atoms of oxygen. Its formula is $C_{57}H_{104}O_6$. A single atom, therefore, must be much smaller than one of these oil molecules. We may summarize these experimental results by saying that the different atoms are certainly less than a hundred-thousandth of a millimetre in diameter, and that the masses even of the heaviest are less than the thousandth of a millionth of a gramme. Other methods, as we shall see later, enable us to determine their dimensions more precisely.

We now come to consider some of the more striking phenomena, apart from chemical interactions, which are explained by the atomic theory. We have already had a hint that the three states of matter—solid, liquid, and gaseous—can be explained by this theory. A liquid differs from a solid in that its constituent particles are more free to move. They can slide about over one another, and it is for that reason that a liquid will take the shape of any vessel into which it is put. Nevertheless, the molecules of a liquid are not completely free to move. Although a liquid can take up any shape, its volume does not alter. In a gas, however, we have the maximum degree of freedom. The molecules of a gas are flying about in all directions with all velocities. A gas can take on any shape, and can fill any volume.

The theory that a gas consists of little discrete particles in motion is called the Kinetic Theory of Gases. The success of this theory in explaining the observed behaviour of gases is a very strong testimony to the truth of the atomic theory. At first sight the idea of explaining the properties of a gas by the motions of its constituent molecules would seem to be hopeless. For there are countless millions of molecules in any appreciable volume of gas. These molecules are perpetually colliding with one another; the direction and speed of any mole-

cule is continually altering. It is obviously impossible to follow the history of any particular molecule in detail, and the whole group of molecules, taken together, forms nothing short of a chaos. But this fact, that the molecular motions are completely chaotic, was seen by James Clerk Maxwell to be the key to the problem. For it enables the law of chances to be applied. We cannot go into the mathematical reasoning here, however.

We know that a gas exerts pressure on the walls of the vessel containing it. This pressure is due to the incessant bombardment of the walls by the flying molecules of the gas. If the gas were compressed into half the space, the pressure would be doubled. This is because the molecules, having only half the distance to go, would rebound from wall to wall twice as quickly, and so each wall would receive twice the number of collisions. Of course, we are here speaking of velocities *on the average*. At any given moment the individual molecules are moving, some faster, and some more slowly. Also, as we have said, their directions of motion are continually changing. But, on the average, as many molecules are flying in any one direction as in any other at a certain average speed, so that each wall receives an equal bombardment. Molecules are such minute bodies, and are so numerous, that this averaging out effect applies to any volume or lapse

of time that we can deal with experimentally. For instance, in each cubic inch of air there are millions of millions of molecules. These molecules are travelling, on the average, with the speed of a rifle bullet, and each molecule experiences about five thousand million collisions every second. It would experience about 200,000 collisions in travelling one inch. Even the rarest vacuum that can be made by modern methods still leaves about 600,000 million molecules to the cubic inch. Yet this degree of rarefaction is so high that a molecule can travel one hundred yards before colliding with another molecule.

We see that molecules are so minute that they pass altogether beyond the limits of our pictorial imagination. We cannot possibly represent to ourselves five thousand million collisions per second. Atoms are even smaller than molecules, for every molecule is composed of two or more atoms linked together. But even atoms are not the smallest entities known to science. As we shall see in more detail later, atoms are composed of electrons, and electrons are altogether more minute than atoms. In the interior of an atom, indeed, an electron, in relative size, would be like a fly in a cathedral. The atomic theory of matter, as we see, leads to very startling conclusions, and naturally we require very strong evidence before we accept a theory so apparently

fantastic. This evidence, as we shall see, is forthcoming in overwhelming strength, and scientific men no longer have any doubt as to the reality of atoms. In the meantime let us turn to another proof of the reality of molecular motions.

In the year 1827, an English botanist named Brown got hold of one of the improved microscopes that had just been introduced. With this instrument he happened to notice, one day, that very small particles suspended in water were in a state of constant agitation. They were perpetually making little movements, and these movements seemed to be entirely at random. Brown announced this queer discovery, but it attracted very little attention. It was accounted for in the vague way that things are accounted for when we consider them too trivial to demand serious investigation. It was pointed out that a very minute degree of vibration would be sufficient to set up such small movements. Or slight inequalities of temperature or pressure would suffice, as when dust particles dance in a sunbeam. It was not for many years that the subject was carefully investigated, and then it was found that none of these explanations would work.

It was found, for instance, that it occurs just as vigorously at night in the country, on a solidly fixed support, as it does in town on a table continually shaken by the passage of heavy traffic. Thus the

vibration hypothesis will not do. Again, experiments were made where the greatest care was taken to maintain uniformity of temperature throughout the drop of water. The movements went on just as vigorously as before. It was then thought that the movements were perhaps in some way due to the influence of light. The drop of water was accordingly illuminated by differently coloured lights of different intensities. All these changes were found to be without any influence on the motions. It became evident that the Brownian movement was not a trivial phenomenon, but had some very deep cause. The movement never ceases. If proper precautions are taken, so that the drop of water does not evaporate away, it may be watched for years. Pieces of quartz have been found containing liquid which must have been shut up in the quartz for thousands of years. The Brownian movement goes on in these liquid inclusions with undiminished vigour.

The correct theory of this movement was worked out by Einstein, and has been experimentally confirmed by Perrin. It is due to the movements of the molecules of the water. The tiny suspended particles are continually being struck by the water molecules. These molecular movements are at random, and therefore they would usually cancel out, the particle being struck equally on all sides. But it would

occasionally happen, by chance, that more molecules were moving in one direction than in any other. If the particle were small enough, it would move in the direction of this resultant impact. The next instant it would happen that the resultant impact was in another direction. And so we get this irregular and incessant movement called the Brownian movement. It is direct testimony to the reality of molecular motions. The phenomenon can, of course, be observed in any liquid, not only water. But, as we should expect, it is less active in the more viscous liquids. Thus in glycerine it is only just perceptible. Gases, of course, manifest the Brownian movement magnificently.

We have seen that the molecular motions of a solid are less than those of a liquid, and those of a liquid less than those of a gas. By increasing the molecular motions of a solid we turn it into a liquid and still further increase turns it into a gas. Now the agent by which we bring about this increase is heat. The effect of heating a body is to increase its molecular motions. In fact, the energy of the molecular motions is a measure of the heat of the body. Heat is, in reality, merely a name for molecular energy—it is the way our senses perceive it. By cooling a body we decrease its molecular energy. If we cool a gas, for instance, its molecules begin to fly about more slowly. Presently they have not the

energy to escape wholly from one another's attractions, and they huddle together. They assume the liquid form. Further cooling deprives them of still more energy, and the molecules are now hardly free to move at all. The liquid has become a solid.

This line of reasoning introduces us to a very interesting fact. For we see that the process of cooling must have a limit. A body cannot have less molecular energy than none at all. If all molecular motions are brought to a standstill, then the body is as cold as it can possibly be. There cannot be a greater degree of cold than that. This lowest possible temperature can be deduced from theoretical considerations. It is the same for all bodies. It is -273° on the Centigrade scale, or -469° on the Fahrenheit scale. At this temperature, which is called the Absolute Zero of temperature, all molecular motions cease. We can get within about one degree of this temperature in our laboratories, and at that temperature not only air, but even the most refractory gases, such as hydrogen and helium, become solid. The regions of outer space, which are often referred to as being at the absolute zero of temperature, are, we have reason to believe, some three or four degrees above this. Thus it is quite possible that the coldest spots in the whole Galactic universe are to be found in the laboratories of certain

modern earthly physicists who specialize in low temperature phenomena.

That heat is really due to molecular motions is a fact that has not always been recognized by the scientific world. In the eighteenth century scientific men supposed that the heat of a body was due to the presence of a fluid called "caloric." This theory was never very satisfactory, but it received its death-blow from Benjamin Thomson, the American adventurer, who, as Count Rumford, had charge of the military arsenal at Munich. Rumford noticed, when boring brass cannon, that the metallic chips thrown off were very hot. On one occasion he bored through a cannon surrounded by a wooden box containing two gallons of water, and in two hours the water was boiling. Rumford came to the conclusion that the heat that could be developed by friction was inexhaustible, and so could not possibly be a material substance. His experiments could only be explained by supposing that heat was a mode of motion, since this was the only thing that could be excited indefinitely. Later on Sir Humphry Davy, working on the same lines, showed that two pieces of ice could be melted by rubbing them together.

We see that the evidence we have already brought forward for the atomic theory is very strong. It explains the behaviour of gases. It explains the

Brownian movement. It accounts for the three states of matter—solid, liquid, and gas. And it gives a very satisfactory theory of heat. We must add to this the fact that the whole of the great science of chemistry, with its hundreds of thousands of detailed results, rests upon the atomic theory.

§ 2. Kinds of Atoms

We have said that there are ninety-two chemical elements, and that all other substances are made up of combinations of two or more of them. Some of these elements are very scarce, others are relatively common. By far the most common element is oxygen, which comprises nearly half of the earth's surface, including in that term all of the earth's crust which is accessible to us, as well as its oceans. The actual percentage of oxygen is 49.2. Next in abundance comes silicon, whose proportion is 25.7. We then have a big drop, and come to aluminium, with a proportion of 7.5. Yet this indicates a relative very great abundance when compared with certain other substances which mankind has known for a much longer time. Copper, for instance, has a proportion of only 0.01 per cent., that is, one part in ten thousand. It seems strange, therefore, that even one hundred years ago aluminium was practically unknown. This was due to the difficulty of separating it from the other substances with which it was combined. Its isolation was first effected by the German chemist Wöhler in 1827. Aluminium

obtained in this way was expensive, costing £30 per pound. Twenty-seven years later a new process brought its cost down to £3 per pound. It was not until 1889 that a young American student, Charles M. Hall, invented a commercially successful process enabling aluminium to be produced at four shillings per pound. Fifty years ago the whole world's production of aluminium per year was less than one hundred pounds. To-day, Great Britain alone consumes 40,000 tons annually.

There are only eight elements present in the earth's crust to a proportion of over 1 per cent. They are oxygen, silicon, aluminium, iron, calcium, sodium, potassium, and magnesium. Together they constitute over 98 per cent. of the earth's crust. If we add four more elements—hydrogen, titanium, carbon, and chlorine—we bring the percentage up to 99.5. Thus the other eighty elements, taken together, make up only one-half of 1 per cent. of the earth's substance. And amongst these comparatively rare elements are some which are not only essential to our modern civilization, but essential to life itself.

A complete account of the elements and their combinations would be equivalent, of course, to an exhaustive treatise on chemistry. We shall here confine ourselves to those properties of the elements which are most significant for modern science. In

particular, we shall be concerned with the difference between their atoms.

The most marked difference between the atoms of different elements is the difference in their weights. All atoms of the same element have the same weight, but the atoms of different elements have different weights. The lightest atom is the atom of hydrogen, the heaviest the atom of uranium. In a table of atomic weights the various atoms are arranged in the order of their weights, beginning with hydrogen and ending with uranium. The weights referred to here are not, of course, the actual weights of the atoms, but their relative weights. Oxygen, as the most frequently occurring element, is a very good standard to take. We call its atomic weight 16. Then the relative weight of the hydrogen atom is 1.008, and the weight of the uranium atom is 238.5. The relative weights of the different atoms are not usually whole numbers. Indeed, whole numbers are decidedly scarce in the atomic table. Helium is a whole number, namely 4, carbon is 12, fluorine is 19, phosphorus 31, and there are some others. But the weight of the chlorine atom is 35.456, silver is 107.88, gold is 197.2, and the majority of the elements have equally complicated figures.

In the days when the technique of weighing was not as accurate as it is now, it was thought that the

weights of all atoms would turn out to be simple multiples of the weight of hydrogen. This suggested the idea that all other atoms were really built up out of hydrogen atoms, and thus suggested that hydrogen is the primordial substance out of which all matter is built. But when the relative weights of atoms were more precisely ascertained, and it was found that hardly any of them are multiples of hydrogen, this idea had to be given up. But we now know that there is a great deal of truth in this idea. We shall see later that there is a sense in which hydrogen really is the primordial substance, and the anomalies of the atomic weights will be explained.

We have so far presented the atom as a small indivisible particle. We may vaguely imagine it as a little hard sphere. Some atoms are heavier than others, and, as their chemical reactions prove, they enjoy very different properties. But the whole assemblage, so far as we have gone, has been presented to us as a sort of chaos. There happen to be ninety-two different sorts of atoms, and apparently we have to accept that as a purely arbitrary fact of nature. But as long ago as 1870 it was shown that a sort of scheme could be traced in the atoms. Certain chemical elements are very alike in their properties. For instance, the elements lithium, sodium, and potassium are alike. Another group is formed by beryllium, magnesium, and calcium. A

large number of such groups can be formed. Now an extraordinary fact emerges when we examine these groups. If we look at our table of atomic weights we find that similar elements occur at regular intervals. Suppose, for instance, that we start with element No. 3—this is lithium. Go on eight places and we reach No. 11, which is sodium. Go on another eight places and we reach No. 19, which is potassium. These three elements, as we have said, are very similar to one another. Suppose now that we begin with No. 4, which is beryllium. Another eight places brings us to magnesium, and a further eight places to calcium. These form another group of similar elements. We shall find the same thing if we start with No. 5 or No. 6, and so on. Newlands, the young Englishman who first noticed this curious recurrence, called it "the law of octaves." He said, "Members of the same group of elements stand to each other in the same relation as the extremities of one or more octaves in music. This peculiar relationship I propose to provisionally term *the law of octaves*." As a matter of fact, however, this law of octaves, although it holds for the early part of the table, has to be modified as we go on, and get amongst the heavier elements. The similar elements become more widely separated. There is a point where the recurrence begins after the eighteenth instead of the eighth member, and, later on still,

after the thirty-second member. The full scheme was brought out by the Russian chemist Mendeléef, who secured the attention of the whole scientific world by using it to prophesy the existence of elements which had not yet been discovered. He saw that there were gaps in the atomic table, and from the positions of the gaps he was able to say what the properties of the missing elements must be. These elements were discovered not very long afterwards, and were found to have the properties predicted by Mendeléef. As a specimen of his accuracy we give the properties he attributed in 1871 to an element then unknown, which he called eka-silicon. This element was found by the German chemist Winkler in 1886, and called by him germanium. We give the properties that he actually found this element to possess.

	Mendeléef's Eka-silicon.	Winkler's Germanium.
Atomic weight . . .	72	72·6
Density	5·5	5·47
Colour	Dirty grey	Greyish white
Density of oxide . .	4·7	4·703
Boiling point of chloride .	Below 100°	86°
Density of chloride . .	1·9	1·887
Boiling point of ethide .	160°	160°
Density of ethide . .	0·96	Nearly 1

Mendeléef's arrangement of the elements is known as the Periodic Table, and it has subsequently enabled many successful prophecies to be made.

Nature always holds surprises for us, however. Radium, whose number in the table is 88, was for long unknown, and its properties were predicted. When radium was discovered it was found to have these properties, but also, in addition, properties of which no chemist had ever dreamt. It is not likely, however, that any hitherto unknown elements will prove to be as startling. We have said that there are ninety-two elements. As a matter of fact, only ninety are known. But we know the places in the table occupied by the two missing elements, and we can say what their properties are.

§ 3. The Structure of Atoms

The Periodic Table of the elements must have aroused the reader's suspicion that atoms are not the simple bodies that we have represented them to be. We have seen that atoms of very different weights may nevertheless be very similar in their properties. What is the cause of this similarity? If atoms are merely little hard spheres, differing only in their weights, we cannot see why there should be this curious recurrence of properties. If, on the other hand, we imagine that an atom is not a simple body, but something possessing a more or less complicated structure, then we can agree that similar structures might manifest similar properties.

We now know that this surmise is justified. The experimental proof that atoms possess structure forms one of the most important chapters of modern science. With this discovery a whole new world was opened up to us, and the whole scientific outlook was revolutionized. In a story based on this discovery, written soon after the event, Mr. H. G. Wells, says: " And we know now that the atom, that once we thought hard and impenetrable, and indivisible

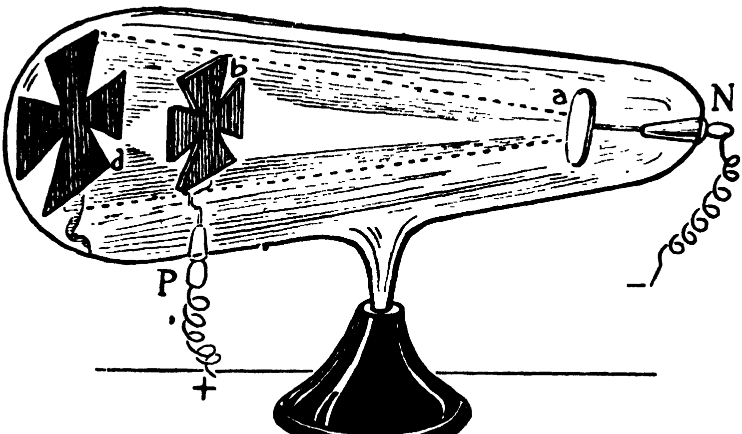
and final and—lifeless—lifeless, is really a reservoir of immense energy. That is the most wonderful thing about all this work. A little while ago we thought of the atoms as we thought of bricks, as solid building material, as substantial matter, as unit masses of lifeless stuff, and behold! these *bricks* are boxes, treasure boxes, boxes full of the intensest force. . . . The energy we need for our very existence, and with which Nature supplies us still so grudgingly, is in reality locked up in inconceivable quantities all about us. We cannot pick that lock at present, but—we will."

Between the years 1895 and 1900 three great discoveries were made, each of which has a bearing on our subject. There was first the discovery of what happens when an electric current is passed through a vacuum tube. Then came X-rays, and finally radium.

Let us take a glass tube in which an almost complete vacuum exists. Through the ends of this tube let us pass two metallic wires which are connected to a source generating electricity. One of these wires is terminated, on the inside of the tube, by a metallic disc. If we now switch on the current, rays of some kind emanate from the metallic disc and proceed in straight lines, producing a florescence at the other end of the tube where they strike the glass walls. That the rays proceed in perfectly

straight lines may be shown by placing an object in the path of the rays—say a cross or a circular disc—when its clear-cut shadow is thrown on the far end of the tube.

What are these rays ? Sir William Crookes, when he first discovered them, thought they must



The straight-line rays of an electric discharge in a vacuum tube.

be a form of light. But he found that if a magnet is brought near, the rays are bent out of their straight-line path. This seemed to indicate that they were material, but they were like no form of matter that Crookes knew. He termed them a *fourth state of matter*, neither solid, liquid, nor gas. Further experiments by Sir J. J. Thomson elucidated their true character. He found that these rays

consisted of electrically charged particles of some kind. (As the reader will see later, there are two kinds of electricity, called positive and negative.) By deflecting these rays under both electric and magnetic attractions he discovered that the electric charges carried by these small particles are charges of negative electricity. But these particles, it could be shown, must be very much smaller than atoms. Lenard had shown that they would pass through sheets of metal—thin sheets, it is true, but thick enough to be quite opaque to light. Particles the size of atoms could not possibly pass through such sheets.

These electrically charged particles were called *electrons*. All electrons are found to be exactly the same, from whatever source they may be obtained. It was immediately surmised that we have here the primordial form of matter, about which scientific men had speculated for so long. All atoms of every kind, it was conjectured, are somehow built up out of electrons. The next step was to find the precise size of these electrons—to determine their masses and the charges of electricity carried by them. This was done. An electron was found to have about 1/1830 of the mass of a hydrogen atom, the lightest of all atoms. We can give the figure for this, although it conveys nothing to the imagination. The weight of a hydrogen atom is such that it

takes 660,000 million billion of them to make up one gramme. An electron is 1/1830 of the weight of one of these atoms. One thousand million million million million electrons would have a mass rather less than one gramme. In actual size the electron has a diameter only one hundred thousandth part of the diameter of a hydrogen atom.

We must here mention one curious and very important point that arises out of this investigation. We have spoken of the electron as an electrically charged particle. And we have already said, in talking about inertia, that electricity manifests inertia. A body carrying an electric charge behaves, in fact, as if its mass had been increased. In view of this fact the question arises, how much of an electron's mass is due to its electric charge? This question has received a very extraordinary answer. We have every reason to suppose that the *whole* mass of an electron is due to its electric charge. An electron is, in fact, nothing but a disembodied charge of electricity. Since all matter is composed of electrons we have to conclude that all matter is electricity. We may call electrons atoms of electricity. This conclusion seems very strange to us at first, for we are accustomed to regarding matter and electricity as utterly different things. But if we remember that electricity possesses the cardinal property of matter, namely, inertia, we shall see

that it is quite competent to play the part of matter.

In trying to find out how atoms are built up out *of electrons*, we are first of all struck by the fact that *all electrons* are negatively electrified, whereas atoms *normally* are not electrified at all. So that the negative charge of an electron must somehow be neutralized when it enters into the constitution of an atom. The only thing that can neutralize a negative electric charge is an equal positive electric charge. So we must assume that positive charges, equal in amount to the negative charges, somehow enter into the constitution of an atom. The theory that was built up on this basis proved so successful that men had no doubt that these positive charges exist, *although* they could not handle them with the facility with which they could handle electrons. These positive charges are called protons. The electric theory of matter asserts, then, that all atoms are composed of electrons and protons.

The next question that arises is, how are electrons and protons arranged within an atom? We shall see presently that radium, amongst other things, shoots out fast-moving and comparatively heavy particles called α-particles. Our question was answered by bombarding thin sheets of metal with these particles. Many of these α-particles passed straight through the sheet of metal, or were only

slightly deflected. But a few of them encountered so intense a repulsive force that they were swung violently round and came out of the metal on the same side they had entered. Now α-particles are positively charged, and it is a well-known fact of electricity that whereas positive charges attract negative charges, two positive charges repel one another, and two negative charges repel one another. It is clear that the α-particles that were repelled must have encountered another positive charge. More, from the intensity of the repulsion it can be deduced that this other positive charge must be extremely concentrated. The picture of the atom that arose from these researches was that of an intensely concentrated central positive charge with electrons circulating round it—rather like a miniature solar system. In all cases, of course, the central positive charge was just large enough to balance the sum of the negative charges on the circulating electrons. If there are ten circulating electrons in an atom, for instance, then there must be a positive charge corresponding to ten protons in its central nucleus.

The task that remains is to find out how the various atoms are built up out of protons and electrons. We shall not go through the ninety known elements in detail, but we shall say enough to show the general ideas involved. The hydrogen atom is

the simplest of all atoms. It consists of one proton with one electron circulating around it. Now, this fact at once shows us a great difference between the proton and the electron, besides the fact that they are charged with opposite kinds of electricity. For we have already said that an electron is much lighter than a hydrogen atom. Roughly speaking, it is eighteen hundred times lighter. But there is nothing in a hydrogen atom but one electron and one proton. It follows that the proton must be responsible for practically the whole weight of the hydrogen atom. It must be, in fact, about eighteen hundred times heavier than an electron. Since the proton, like the electron, is composed wholly of electricity, the fact that it is eighteen hundred times heavier means, curiously enough, that it is eighteen hundred times smaller. It is its greater concentration that gives it its greater weight.

Next to hydrogen in our table of the elements comes helium. This atom has two circulating electrons, and therefore, we would suppose, two protons in its nucleus. But here, already, we have an example of Nature's complication. If we look at the table we see that helium is not twice as heavy as hydrogen, but just about four times as heavy. Since practically all the weight of an atom comes from its protons, we see that the nucleus of a helium atom must possess four protons. But this would

make its positive charge twice as great as it ought to be in order to balance the two circulating electrons. This difficulty is got over by the fact that the helium nucleus is partly neutralized. In some way that we do not quite understand yet, two electrons are combined with the four protons in the nucleus, thus bringing the positive charge down to the right amount. Thus we see that already, with our second step in the table, the nucleus of an atom has a complicated structure. It consists both of protons and of a smaller number of electrons. And, circulating round this nucleus are other electrons equal in number to the protons that remain unneutralized.

We shall have more to say about the structure of the atom later, but in the meantime let us turn to the other two discoveries mentioned—X-rays and radium.

Towards the end of 1895, W. C. Röntgen was experimenting with a vacuum tube in his laboratory at Wartzburg. He was repeating the experiment we have already described, passing an electric current through the tube and studying the rays. It so happened that he one day had occasion to pick up an unused and protected photographic plate that he kept in the room, and for some reason he developed this plate. He found, on development, that the plate had distinct markings on it. This fact aroused his curiosity, and he undertook experiments to find the cause of these markings. He found that a

radiation, capable of affecting sensitive plates, emanated from the vacuum tube when the electric discharge was passing. He also found that this radiation arose at that part of the glass walls of the tube that was struck by the rays created in the tube by the electric discharge. Röntgen called this new emanation X-rays. These X-rays were found to possess remarkable properties. They proceeded in straight lines, like light, but none of the substances that refracted light could refract these rays. They were not electric particles of any kind, for they could not be deviated from their course by a magnet. Further, they were able to pass through many substances opaque to ordinary light, and even to ultra-violet light. Different theories as to the nature of these rays were put forward, but we shall not discuss their nature here. It suffices to say here, that though invisible, they are a very penetrating kind of light, and we shall discuss their nature when we discuss light in general. For our present purpose the great interest of this discovery is that it led to the even more important discovery of radium.

Röntgen's discovery of X-rays led Henri Becquerel to undertake certain researches on uranium compounds, in connection with their phosphorescence. He found that the metal uranium and all its compounds emit rays which, like Röntgen's X-rays, pass through substances opaque to ordinary

light, and affect a photographic plate. Becquerel naturally concluded that these rays came wholly from the uranium. But on testing a specimen of the chief ore of uranium, pitchblende, a mineral which came from northern Bohemia, he was puzzled to find that it gave a much more powerful effect than the amount of uranium in it warranted. He concluded that, concealed in the pitchblende, was an element much more powerful than uranium. This was the point at which the Curies took up the work.

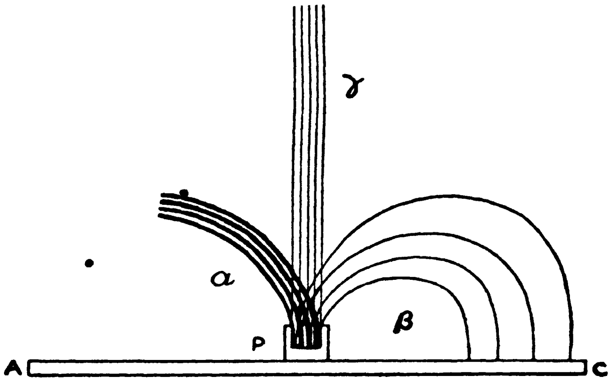
Madame Curie was a Polish refugee who had been stranded in Paris, and had been put to wash bottles in the physical science department of the Sorbonne. Later she was promoted to assist a young student, Pierre Curie, in research work. This collaboration speedily led to the marriage of the young couple. They were asked if they would undertake to track down the mysteriously powerful substance concealed in pitchblende, and they enthusiastically agreed. They had no money, but they wrote to the Austrian Government, and soon, from the mines of Joachimstal, a ton of pitchblende arrived in Paris. The Curies immediately got to work. For months they laboured, filtering and separating one impurity after another from their mound of pitchblende. " We lived in a preoccupation as complete as that of a dream," remarked

Marie years later. After two years of work a substance was isolated which was more than two million times as active as uranium. This substance was named Radium. It was so active that it glowed in the dark, and continually gave off appreciable amounts of heat. Its radiation coloured diamonds and glass tubes. It electrified the air about it, and penetrated opaque objects.

The correct explanation of this radiation was given, in 1902, by Rutherford and Soddy. The radiation from radium has three ingredients, which are called α-rays, β-rays, and γ-rays. α-rays are positively charged particles. They are comparatively heavy particles, having about four times the mass of a hydrogen atom, and they move at very considerable speeds, varying from about nine thousand to about thirteen thousand miles per second. β-rays are electrons. Thus the β-particles are very much lighter than the α-particles. Their speeds, however, are much greater. The fastest-moving β-particles move with speeds that are within one or two per cent. of that of light itself. The third type, the γ-rays, are not particles at all. They are akin to X-rays, but are even more penetrating than X-rays. Nothing that we can do to radium—no extremes of temperature or pressure to which we can subject it—has the slightest effect on these processes. They are due, as has been shown by

numerous experiments, to the actual disintegration of the radium atom. The nucleus of the radium atom is spontaneously breaking up, and these radiations are its products.

The nucleus of the radium atom, like that of all atoms except hydrogen, is a complex affair. It contains both protons and electrons. Now all the



The three kinds of rays shot out by radium.

chemical properties of an atom depend on the resultant positive charge on its nucleus. In the atom of gold, for example, we have one hundred and ninety-seven protons in its nucleus, combined with one hundred and eighteen electrons. We have, therefore, seventy-nine protons left unneutralized, and so the positive charge on the nucleus of the gold atom is seventy-nine. To compensate for

this, and to make the whole atom electrically neutral, we have, of course, seventy-nine electrons circulating round the nucleus. If we look at our table of the elements we shall find that gold occupies place No. 79 in that table. The table has been so constructed, in fact, that the place number of an atom, called its *atomic number*, gives us also the positive charge on its nucleus. This atomic number is a much more important thing about the atom than its atomic weight. We shall describe later the brilliant research by which the atomic number, which is the positive charge, of an atom was determined. As we see by looking at the table, the atomic numbers are, for the most part, in the same order as the atomic weights. There are only one or two places in the table where the order differs.

The general principle is, we see, quite simple. The atomic weight of an atom tells us how many protons there are in its nucleus. The atomic *number* tells us the positive charge on the nucleus. Other questions we may ask can be immediately answered if we know these two facts. We may want to know, for instance, the number of circulating electrons the atom possesses. The answer is that there must be as many as will compensate exactly the positive charge. So the number of circulating electrons must be equal to the atomic number of the atom. Or we may ask how many electrons there are in the nucleus.

To find this we subtract the atomic number from the atomic weight. The result tells us how many protons have been neutralized, and this, of course, is equal to the number of electrons present in the nucleus.

We now return to consider the disintegration of radium. There are several substances, it may be mentioned, which are disintegrating. Radium is merely the most active of them. We have said that the α-particles are positively charged, and that they are about four times as heavy as a hydrogen atom. Rutherford showed that they are, in fact, helium atoms which have lost their two circulating electrons. A α-particle is, indeed, the nucleus of a helium atom. It consists of four protons combined with two electrons, and therefore manifesting a positive charge of two. It is an extraordinary fact that helium nuclei are shot bodily out of the radium nucleus. Helium nuclei, it has been discovered, are very stable structures, and they enter bodily into the constitution of the nuclei of more complicated atoms.

Radium shoots out both helium nuclei and electrons, and by doing so it changes into a different substance. We can see that this must be so. When a helium nucleus is shot out it carries away from the radium nucleus four protons and two electrons. The atomic weight of the radium atom is diminished by four and its positive charge, and therefore its atomic

number, by two. It has become a lighter element, and it has dropped two places down in the atomic table. Thus it has become an altogether different substance. By shooting out an electron from its nucleus it undergoes a rather different change. Its atomic weight is not affected, for, as we know, the weight of an electron is altogether insignificant. But the electron, since it has come from the nucleus, has left behind it an unneutralized proton. Hence the positive charge has increased by one unit, and therefore the atom has gone up one place in the table. Thus, again, the radium atom has become a different substance, but in the other direction, as it were. When a radium atom disintegrates the substance it changes into is itself a disintegrating substance. And it gives rise to a further disintegrating substance, and so on. There is quite a long series of these changes, and at the end of them all we find we are left with lead. Lead seems to be a perfectly stable substance. So far as we know, it is not disintegrating.

In any sample of radium only a certain fraction of its atoms are disintegrating at any one time. This fraction remains constant. That is to say, whether the quantity of radium be large or small it is only that fraction of it that is disintegrating. So that as our sample of radium disintegrates and becomes less and less, so the amount of radium disintegrating

becomes less, always keeping the same fractional value. Thus it would take an infinite time for any sample of radium wholly to disintegrate. A half of any quantity of radium would disintegrate in 1,700 years. At present we have no knowledge at all of what causes a radium atom to disintegrate. So far as we are concerned it is a matter of pure chance whether any particular radium atom will break up at any particular time.

The lead into which radium finally passes has not quite the same atomic weight as ordinary lead. This statement contradicts the chemical law we gave previously, which says that all atoms of the same element have the same weight. And, indeed, recent investigations have shown that the law is incorrect. Most elements have atoms of different weights. Thus the element krypton has atoms of weights 78, 80, 82, 83, 84, 86. In the table of atomic weights its weight is given as 82.9. But this is purely an average weight, due to the fact that in any specimen of krypton that we can handle chemically the various krypton atoms are mixed up. Chlorine, whose atomic weight is given as 35.456, is made up of two groups of atoms, having weights 35 and 37, mixed in the proportions of about three to one. Selenium, whose atomic weight is given as 79.2, is made up of atoms whose weights range from 74 to 82.

It is easy enough to see on our theory of the

atom how this state of affairs can come about. Suppose we have an atomic nucleus containing ten protons and five electrons. The positive charge will be 5, and the atomic weight 10. Or suppose that we have twelve protons and seven electrons. The atomic weight is now 12, but the positive charge is still 5. Since all the chemical properties of an atom depend on its positive charge, we are still dealing with the same element. But we have two atoms of different weights. Such atoms are called Isotopes. The fractional values that chemists give for so many atomic weights are really only average values. When the different atoms of the same element are disentangled they are all found to have weights which are whole numbers.

This fact seems at first somewhat surprising, for the weight of hydrogen is not exactly 1, but 1.008. Whole numbers, therefore, are not exact multiples of the weight of hydrogen. If there are four protons in the helium atom, it seems that it should weigh four times as much as the hydrogen atom, which contains only one proton. That is, it should weigh 4.032 instead of 4 exactly. The reason for this is very interesting, and also throws light on the fact we mentioned before, namely, the great stability of the helium nucleus. The fact is that the formation of any complex nucleus, such as the helium nucleus, is attended by a loss of energy, and energy, as we shall

see later when we come to discuss relativity theory, has weight. The difference between 4.032 and 4 exactly represents the weight of the energy lost in the formation of the helium nucleus. The energy so lost is really immense. It is sixty-three million times greater than the energy expended in ordinary chemical processes. Usually a few degrees of heat are sufficient to split up a chemical compound. We should have to use sixty-three million times that energy to break up the helium nucleus. That figure gives us a measure of the stability of helium. Even the immensely energetic processes going on in radium do not dissociate the helium nucleus. As we have seen, it is shot out bodily.

When α and β particles from radium are shot through a gas they collide with its molecules and knock electrons out of them. Water vapour readily condenses on molecules in this condition. This is the basis of a brilliantly successful method which enables the actual paths of α and β rays to be photographed. A vessel of air is filled with water vapour, and α and β rays are shot through it. If the vessel is now suddenly cooled the water vapour condenses as a sort of fog on the molecules which have been struck. At the same moment the vessel is illuminated, and a photograph taken of the foggy trails, showing the actual paths which have been taken by the α and β particles. This is one of the most

ingenious and beautiful experiments in modern science.

Further developments of the atomic theory will be dealt with in a later section. These developments are so strange that they require a new set of ideas to deal with them, and these ideas require a knowledge of certain branches of physical science that we have not yet touched upon. Partly for this reason, and partly for its own intrinsic interest, we shall now deal with the subject of light.

SECTION IV.—RADIATION

RADIATION

§ 1. Its Velocity

It needed a great imaginative effort to realize that light is something that moves, and moves at a definite speed. It seems so natural that, when we open our eyes, we should *see*, that light, like space itself, seems to be a circumambient something to which the notion of velocity cannot be applied. We do not know the first man to whom the notion occurred that light moved, but the first man who made a really scientific use of the idea seems to have been the Danish astronomer Römer. In the year 1676 he was watching the motions of the four great satellites of the planet Jupiter. In the course of their revolution round Jupiter there came a moment, of course, when they disappeared behind the planet, and another moment when they emerged again. Each satellite disappeared for a certain length of time. Römer kept careful count of the time these disappearances lasted, and he was astonished to find that these times were not always the same. This was puzzling, because he could not suppose that a satellite altered its speed. It could not be going round Jupiter sometimes faster, and

sometimes slower. He then noticed that this apparent variation in speed was connected with the relative motions of Jupiter and the earth. The motions of the earth and Jupiter in their orbits round the sun are such that Jupiter is sometimes approaching the earth and sometimes receding from it.

Suppose that Jupiter and its satellites are receding from the earth. At a certain moment one of its satellites is seen to disappear behind Jupiter. After a time it goes round the back of Jupiter and is seen to reappear on the other side. But in the meantime Jupiter has been receding from the earth. The light from the reappearing satellite has a longer distance to travel, therefore, than had the light from the disappearing satellite. Now suppose that the conditions are reversed, and that the satellite's revolution is observed while Jupiter is approaching the earth. Here the opposite occurs, and the light from the reappearing satellite has a smaller distance to traverse than had the light from the disappearing satellite. If light takes time to travel, then the intervals in these two cases between the disappearance and the reappearance cannot be equal. This solution, that light does not travel instantaneously, but takes time to travel, occurred to Römer. From his observations he worked out the velocity of light. He made it 192,000 miles per

second. His apparatus was what we should regard as primitive, and his value is not correct. It is too high. From very refined modern observations we know that the velocity of light is 186,300 miles per second. At this rate light from the sun takes about eight minutes to reach us.

The fact that light takes time to travel immediately raises the question as to what happens to it in the meantime. How does light reach us? There have been two great theories about this. One says that light consists of little particles which are shot by the luminous object into our eyes, and the other says that light is a wave motion, like the waves that spread out when a stone is thrown into a pond. But the waves in a pond require water to travel in. What do light waves travel in?

In order to answer this question scientific men imagined a medium they called "ether," a sort of jelly filling the whole of space. They found that innumerable things about light can be explained if we suppose light to consist of wave motions in this universal medium. This theory became very popular, and entirely replaced the theory of light as little particles—the corpuscular theory, as it was called. Nowadays we have a curious blend of both theories. But before we discuss that we must first understand the evidence for the wave theory.

At first sight there seems to be one obvious

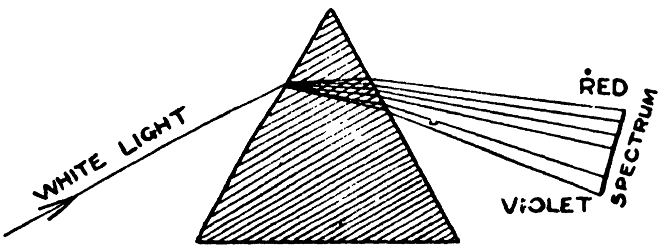
objection to the wave theory. It is a matter of common experience that light travels in straight lines. An object, whether it be circular, square, or any other shape, throws a perfectly defined shadow. The rays of light evidently go straight past its edges and show no tendency to bend round. Would waves *do that ?* We know that we can hear sound round obstacles, and we know that sound travels as waves in the air. If light is a wave motion, why does it not bend round obstacles, instead of throwing such well-defined shadows ? The answer is that light does bend round obstacles, but that the bending effect is very small. If light be passed close to the edge of an opaque object it is found that it does not give a perfectly sharp shadow. Similarly, light admitted through a very small aperture into a darkened room diverges in all directions, just as sound does when admitted through an aperture a few feet in diameter. These phenomena require the wave theory of light to explain them. The reason they occur on such a small scale is because the waves of light are exceedingly minute.

§ 2. Light Waves

Light waves are of different lengths, depending on the colour of the light. The longest waves are those of red light, and the shortest those of violet. Red light has a wave-length of three one-hundred-thousandths of an inch. The wave-length of violet light is about half this. We have already said that light travels at about 186,000 miles per second. This velocity is the same for light of all colours. In one second, therefore, the light-waves entering our eye would fill up a length of 186,000 miles. Thus, in the case of red light, about four hundred million million waves enter our eye every second, and for violet light about twice as many.

Ordinary white light is composed of all the different colours mixed together in certain proportions. When white light is passed through a prism and allowed to fall upon a screen we get a coloured band, ranging from red at one end to violet at the other. This is the *spectrum*. The reason for this splitting up of white light into its constituent colours depends on the familiar fact that light is bent when it passes from one medium to another. We know

that a stick, partly in and partly out of water, looks bent. The reason is that the light from the immersed portion of the stick, on entering the air, is bent through an angle and so reaches our eye in a different direction. Similarly, light passing from air into water, or from air into glass, is bent. But the amount of the bending depends not only on the properties of the two media, but also on the wave-length of the light employed. In passing through a



The spectrum.

glass prism red light is deviated least, and violet most, the other colours being deviated by intermediate amounts. Thus the prism spreads out the constituents of white light in the order of their wave-lengths.

The theory that light is a wave motion receives very strong support from a phenomenon called Interference. Let us cause a beam of light to pass through a narrow slit in a shutter. Now let this beam fall upon a screen perforated by two pinholes

very close together, and let the two small pencils of light that emerge from these pinholes fall upon another screen. We shall find that the place on the screen where these two pencils overlap is not evenly illuminated, but is covered by a series of bright and dark bands alternating with one another. How are these dark bands to be explained? How can the superposition of one light on another cause darkness? If light consists of little luminous corpuscles it is manifestly impossible. But the phenomenon can be explained if we suppose light to consist of waves. For if two trains of waves are superposed it can happen that the troughs of one set coincide with the crests of the other. Thus there is no resultant wave-motion; it is flattened out, as it were. The two trains of waves cancel each other. Elsewhere on the screen we shall find that the two trains of waves reinforce one another. Trough coincides with trough, and crest with crest. The result is a bright band. We may mention that no actual destruction of light takes place in this experiment. The light that is absent from the dark bands is heaped up in the bright bands. This experiment is a very strong support, in fact it may be described as the strongest single support of the wave theory of light.

But the wave theory applies to much more than the range of vibrations that constitute visible light. Waves shorter than the violet or longer than the red

do not affect our sense of sight, and so are invisible, but we have plenty of evidence that they exist. Stretching away below the waves of red light we have waves of radiant heat, and below those we have the waves of wireless telegraphy and telephony. These waves, instead of being minute fractions of an inch, are, in some cases, thousands of yards in length. In the other direction we encounter shorter waves than the violet, waves which do not affect the eye, but which affect a photographic plate. These are the so-called ultra-violet rays. When we come to waves of from one hundredth to one thousandth of the length of visible light waves, we find that we are dealing with X-rays. Still shorter are the γ-rays from radium, which have wave-lengths of the order of one hundred thousandth of that of visible light.

The penetrating power of radiation depends on its wave-length; the shorter the wave-length the greater the penetrating power. Ordinary light, as we know, will barely penetrate the very thinnest sheets of gold-leaf. X-rays will pass through a fraction of an inch of gold or lead, while very penetrating γ-rays will pass through some inches of lead.

In recent years a very much more penetrating type of radiation has been discovered. This radiation seems to come from outer space, for as we ascend higher from the surface of the earth, so we find the

radiation growing stronger. It is as strong by night as by day, so it does not come from the sun. Since the sun is just a typical star there is no reason, therefore, to suppose that it comes from the stars. There are different theories as to its origin. One theory supposes that it comes from the building-up of atoms in remote regions of space. Another theory supposes, on the contrary, that it comes from the annihilation of atoms. Both these theories assume that it exists in wave-form, like X-rays or γ-rays, but very much shorter. Another possibility is that the radiation does not consist of waves at all, but of corpuscles, like the β-rays from radium. This radiation is so penetrating that it will pass through sixteen feet of lead. Only corpuscles travelling with practically the speed of light could have this penetrating power. If the radiations are waves, then they must be very minute. It can be calculated that the wave-length necessary must be of about the same magnitude as the diameter of an electron. The evidence is growing, however, that this radiation is corpuscular in character.

§ 3. Spectra

The light from an incandescent gas does not include all the wave-lengths that belong to the visible spectrum. When its light is passed through a prism we do not get a continuous coloured band extending from red to violet, but a number of isolated bright lines with dark gaps between them. Corresponding to each of these lines is a definite wave-length, which is known at once when we know the position of the line in the spectrum. Knowing these wave-lengths, the spectroscopist knows the substance he is dealing with, for each substance sends out its own characteristic group of lines.

A gas absorbs the same kind of light that it emits. This is a very interesting and important law. If we pass light containing all colours, say, light from an arc lamp, through a gas, we shall find dark lines in the spectrum, and these lines occur at the same places as the bright lines sent out by that gas when it is incandescent. This is the principle by which we have discovered the constitution of the heavenly bodies—or, at least, of their outer layers. The light from the intensely glowing body of the

sun, for example, has to pass through its relatively cool outer layers before it reaches us. These outer layers are composed of the gases of various chemical elements, and each of these gases absorbs the particular wave-lengths characteristic of it. Thus when the light from the sun is passed through a prism and spread out in a spectrum, we find that this spectrum is crossed by a large number of dark lines. These lines can be disentangled into groups, each group being characteristic, as we know from experiments in the laboratory, of a particular element. Thus we can say definitely that such and such elements are present in the sun's atmosphere.

The stars have been subjected to the same analysis, and, as in the case of the sun, their atmospheres are found to be composed of known elements. By far the most abundant element in the stellar atmospheres is hydrogen. Next comes helium, and then oxygen. Corresponding to every sixty atoms of oxygen, we have ten thousand of helium, and no less than five million of hydrogen. But even oxygen is more abundant than the nine next most abundant elements taken together. These constituents are metallic gases, sodium, aluminium, iron, and so on.

Besides its visible spectrum an element possesses also an X-ray spectrum. X-rays are produced by an apparatus which consists essentially of a vacuum tube in which a stream of electrons is produced in

the way we have already described. These electrons are caused to bombard a metal plate, usually platinum or tungsten, and the bombardment produces X-rays which radiate from the plate. These X-rays are of two kinds. Some are produced merely by the stoppage of the electrons. Others come from the atoms of the material which is being bombarded. And these latter kind of X-rays are found to be entirely characteristic of the substance that emits them. Each substance has a characteristic X-ray spectrum.

The discovery and measurement of X-ray spectra was due to a very ingenious device. Visible spectra are produced, not only by passing light through a prism, but also by passing light through what is called a diffraction grating—a method which has certain advantages. A diffraction grating consists essentially of a sheet of glass on which a large number of very fine lines have been ruled very close together. The lines should be parallel and equidistant. The closeness of the lines depends on the wave-length we wish to measure. The distance between adjacent lines, should, in fact, be of the same order of magnitude as the wave-lengths. It is a great tribute to human ingenuity that such gratings can be constructed even for ordinary light. Gratings containing a thousand lines to a millimetre have been ruled. But X-rays, as we have seen, have a wave-

length a thousand times shorter than visible light. It is obviously hopeless to try to rule a million lines to a millimetre.

The German physicist, von Laue, had the brilliant idea that such gratings already exist in nature. Certain mineralogists and mathematicians had long been concerned with the beautiful symmetry of crystals. They had worked out that the regular shape and structure of these objects must be due to the regular spacing of the atoms composing them. These atoms are arranged in definite patterns, one layer behind another. And the distances between these atoms, it could be worked out, must be of the same order of magnitude as the wave-lengths of X-rays. Here, therefore, ready to hand, were the desired diffraction gratings! This idea proved to be a brilliant success. It is now possible, using this method, to obtain photographs of X-ray spectra. And, of course, all discussion of the nature of X-rays was finally cleared up by this discovery. It became evident that they are waves, and waves of very short wave-length.

As a result of these researches we now know that the wave-lengths of X-rays vary within fairly wide limits, according to the conditions of their emission. They vary in length from about 12×10^{-8} cm. to $.3 \times 10^{-8}$ cm. The shorter the wave the greater its penetrating power or " hardness."

We have said that the substances bombarded by electrons in a vacuum tube send out characteristic X-rays of their own. All chemical elements, under bombardment, do this. And we find that the greater the atomic number of the element, the harder are the X-rays it emits. In fact, the increase in hardness takes place in a perfectly regular step-by-step manner as we go through the atomic table. This progress is so regular that scientific men have not hesitated to arrange the elements in accordance with it. It is on the strength of this, indeed, that the present order of the atomic numbers has been adopted. Moseley, a brilliant young English man of science who was killed in the war, was the first to show the perfect orderliness of this progression.

Moseley's first group of photographs began with calcium, whose atomic number is 20, and ended with copper, whose atomic number is 29. These elements were successively placed in a vacuum tube and bombarded by electrons. The resulting X-rays were analysed by passing them through a crystal. Moseley found that, as the atomic number increases the X-rays emitted become harder; that is, of shorter wave-length. As we have said, this occurs in a perfectly regular manner. In Moseley's original research there was a gap between calcium and titanium. This gap was immediately revealed by the X-ray spectra. In passing from calcium to

titanium, the jump in hardness was twice what it should be, revealing that one element had been omitted. This missing element is now known. It is the rare substance named Scandium, with atomic number 21. Another point brought out by this research is that the X-rays emitted by a bombarded substance come directly from the atoms of that substance. If we take a substance such as brass, which is an alloy of the two elements copper and zinc, we do not get an X-ray spectrum intermediate between those of copper and zinc. We get two distinct spectra, one being the spectrum of copper and the other that of zinc. And we may mention that, where the order of two elements by weight is inverted in the atomic table, the heavier element being placed before the lighter one, this inversion is completely confirmed by the X-ray spectra. Nickel and cobalt form such a pair. Cobalt is heavier than nickel, with an atomic weight of 58.97 as against an atomic weight of 58.60. Nevertheless, the chemists put cobalt before nickel. They did this after considering the whole complex of the physical and chemical properties of these two elements. And their decision is entirely borne out by the X-ray spectra. The method of analysing X-ray spectra gives such unambiguous results that we can have every confidence in the order we derive from it.

Later on we shall say something about the light thrown by spectroscopy upon the structure of the atom, but in the meantime we shall refer to one or two other results of this very important branch of science.

§ 4. Further Applications

It is interesting to reflect that August Comte, the father of the positivist philosophy, and who considered that science alone was a proper occupation for a mature mind, nevertheless pointed out that there was certain information that science could never give us. We could never know, he said, the chemical constitution of the stars, for the stars are inaccessible to us. He wrote, of course, before the days of spectrum analysis. But the light from a star does more than tell us about its chemical constitution. It can give us information about its temperature and also about its density. Further, it enables us to measure just that component of a star's velocity that we cannot measure by ordinary means, namely, its motion in the line of sight.

Stars are so remote from us that they are mere points of light in a telescope, and their direct motion towards us or away from us makes no faintest difference to their appearance. They do not seem to become larger or smaller. Of course, if they are moving across the sky then, after a sufficient time, their position in the sky is seen to be different, and

we can measure this sideways motion. But the true motion of a star usually involves both factors. Usually it is not only moving across the sky, but it is also moving to or from us. To know its true motion we have to know both components.

The spectrum of a star enables us to measure this to or fro motion very simply. Let us imagine a regular series of waves in water, the waves being a certain distance apart. Then a certain number of these waves will pass a stationary ship in, say, one minute. But if the ship is advancing to meet the waves, then obviously more waves will pass it in one minute. And if it is moving in the same direction as the waves, then fewer will pass it in a minute. Now suppose a star is moving towards us. So far as the relative motion of the star and the earth are concerned, it is the same thing if we suppose we are moving towards the star. In either case we encounter more light waves in a given time than if there were no motion. But we have already seen that the *colour* of the light we perceive depends on the number of light-waves that enter our eye in a certain time. The colour red corresponds to the least number of waves, and the colour violet to the greatest number. The effect of the star's motion towards us, therefore, is to change the colour of its light. The lines of its spectrum experience a shift towards the violet end of the spectrum. By comparing the positions of

these lines with the positions of the lines emitted by the same gases on earth, we can calculate the velocity of the star towards us. Similarly, if the star is moving away from us, the lines of its spectrum shift towards the red end of the spectrum. This principle has been used, also, to measure the rotation of the sun and planets. As the sun rotates on its axis one half of the circle we see is moving towards us, and the other half away from us. The spectroscope enables us to measure this motion.

§ 5. Science and Explanation

We have said that the signals of wireless telegraphy and telephony, radiant heat, light, X-rays, γ-rays, are all wave motions. It is possible, also, that the recently discovered very penetrating radiation called "cosmic rays" is also a wave motion. But waves must be waves of something, and, so far, we have said nothing about the medium in which these waves are supposed to exist. A few years ago we would have had no difficulty in describing this medium. We would have talked about a universal medium called the "ether," which was supposed to fill all space, and which enjoyed the most remarkable properties. Its properties differed, to some extent, according to the authority who was describing it, but they all agreed on its existence. It was, in some ways, like a vibrating jelly. But gyroscopic motions also went on in it. There were rotating motions and sliding motions. As it was further investigated it became more and more complicated, until it is literally true to say that it became too complicated for belief. Scientific men gradually came to realize that they must be on the wrong track. They had

tried to make light waves and the other waves of radiant energy rather too concrete. They had tried to construct, theoretically, a great mechanical medium on the basis of their experience of ordinary matter. This seemed, at the time, a perfectly natural thing to do, but we now know that the inner processes of nature do not lend themselves to description in mechanical terms.

But if we are to give up picturing nature in the terms with which we are familiar, how are we to picture it ? The only possible answer at the present time is that we do not know. The workings of nature, as we have come to know them during the present century, are so unlike our ordinary experience that we cannot picture them at all. We have to be content with a more abstract, a less intimate, kind of knowledge. We can work out the laws that natural phenomena obey, but we cannot picture to ourselves anything that would behave in that manner. Take, for instance, the question of the propagation of light. We have said that it is propagated in the form of waves. This is quite true. There are numerous experiments, like the interference experiment we described, which prove it. But, as we shall see later, there are other equally indubitable experiments that prove that it is propagated in the form of little corpuscles. So far as we can make out, light is both a wave and a corpuscle at the same time.

How can this be ? At present we have no idea. We can work out the laws obeyed by this mysterious entity, light, but we cannot picture to ourselves the sort of thing that is obeying them. We shall find a similar difficulty when we come to study the electron more closely. Physical science, at the moment, has passed beyond the resources of the pictorial imagination.

In spite of these limitations there is still a good deal that can be said about the wave-theory of light. The greatest scientific discovery of the nineteenth century was Maxwell's electromagnetic theory of light, which explains light waves as consisting of electric and magnetic forces. But before we discuss this we must say a little about electricity and magnetism.

§ 6. Electricity and Magnetism

If a plate of glass and a plate of vulcanized india-rubber are rubbed together it is found that some force is required to separate them, and if they be not separated too far, they are found to attract one another. If a second plate of glass and of india-rubber are treated in the same way we find that either plate of glass attracts either plate of india-rubber, but the two plates of glass repel one another, as do the two plates of india-rubber. Bodies in this condition are said to be electrified. But we see that the electricity on the india-rubber differs in some way from that on the glass, since it repels what the other attracts, and vice versa. There are, in fact, two kinds of electricity, and they are called positive and negative. There is no deep meaning about the names; they serve merely to distinguish the two kinds of electricity from one another.

In general, any two bodies, after having been rubbed together, become more or less electrified. Some bodies, when electrified at one part, are immediately found to be electrified all over. Such

bodies are called good conductors of electricity. With other bodies electrification spreads over them only very slowly. Such bodies are called non-conductors, although it would be more proper to call them merely bad or slow conductors. All metals are conductors, and so is water in its ordinary state. Living plants and animals, being for the most part pervaded by watery fluids, are conductors. Air and other gases are non-conductors. Such substances as glass, shellac, india-rubber, silk, wool, sulphur, amber, are also ranked amongst the non-conductors.

The attractive force between two electrified bodies was found by Coulomb to be the same as Newton's law of gravitation. It varies inversely as the square of the distance. If the electric charges on the bodies are increased, the distance remaining the same, then the force of attraction is increased in the same proportion. Exactly the same law applies if the two bodies repel one another instead of attracting one another.

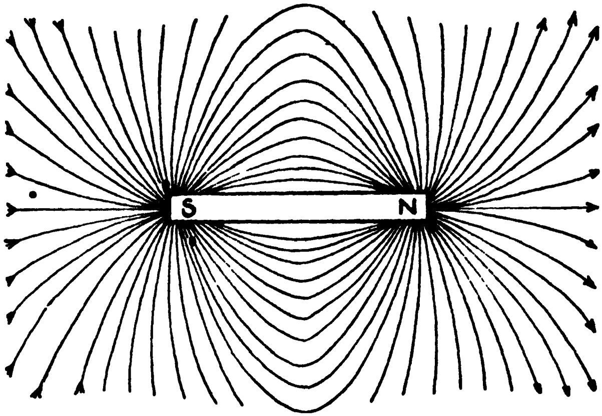
So far we have been speaking of electrification produced by friction. This was the only kind of electricity that had been investigated up towards the end of the eighteenth century. But towards the end of that century Luigi Galvani, Professor of Anatomy at Bologna, happened to notice that a dissected frog was violently convulsed merely on being touched

with a scalpel. This queer fact led him to make experiments, and he found that whenever he connected the muscles and nerves of the frog by a metal, the limbs of the frog were convulsed. In his own words: "While I with one hand held the prepared frog by the hook fixed in its spinal marrow, so that it stood with its feet on a silver box, and with the other hand touched the lid of the box, or its sides, with any metallic body, I was surprised to see the frog become strongly convulsed every time that I applied this artifice." Galvani believed that these effects were due to a peculiar fluid contained in the nervous system, and which passed to the muscles by the metallic connection. Electricity, in those days, was supposed to be a "fluid," and Galvani believed the peculiar fluid in the frog's nervous system to be the ordinary electric fluid. Another school maintained that it was a special sort of fluid, and they called it Galvanism, or Animal Electricity, a term that is still encountered amongst certain popular beliefs. Alessandro Volta, however, took a step forward when he declared that the physiological peculiarities of the frog had nothing to do with the matter, and that the frog merely played the rôle of a moist body. Fabroni, a member of Volta's school, went still further when he stated that the galvanic effect was inseparably connected with chemical action. This view was ultimately shown to be the

right one. Electric currents can be produced by chemical actions. Furthermore, electric currents can produce chemical effects. It was shown that an electric current could decompose water into its constituents, hydrogen and oxygen. It can also decompose solutions of metallic salts. Sir Humphrey Davy, with one of his typical flashes of insight, asserted that all chemical action was at bottom electrical.

The next great advance in electrical science brought magnetism into the scheme. The phenomena of magnetism had long been known, of course. The word comes from the Greek province Magnesia, where pieces of iron ore were found which had the power of lifting small masses of iron, such as filings or small nails. Subsequently these iron ores were found in many parts of the world. In England they were called loadstones or lodestones. An artificial magnet may be produced by stroking a strip of steel from end to end, always in the same direction, with one of these pieces of iron ore. The artificial magnet so produced is often stronger than the original, although the latter has lost none of its power. The artificial magnet shows clearly a certain property which is common to all magnets, and that is that two points of it, usually the two ends, are more strongly magnetized than the other parts. These are called the "poles" of the magnet. Iron

filings adhere in thick bunches to the two poles, while the rest of the magnet may be quite clear from them. If a piece of smooth cardboard, sprinkled with iron filings is laid on a magnet, and the card is then tapped, the iron filings arrange themselves in regular curves symmetrical about the centre of the magnet.



Lines of force of a magnet.

(See diagram.) These curves correspond to what are called the " lines of force " of the magnet.

If a magnet is suspended so that it can turn freely, then, as we know from observation of an ordinary compass needle, it turns so that one of its poles is pointing north and the other south. For this reason we speak of the north pole and the south pole of a magnet. The north pole of one magnet repels the north pole of another. Similarly, two south poles

repel one another. But north and south poles attract one another. We see that north and south poles behave, in this respect, like positive and negative charges of electricity.

With this preliminary information we can now turn to consider the relations between electricity and magnetism. That such a connection exists had been surmized long before it was proved. It had been known from the middle of the eighteenth century, for instance, that lightning could magnetize steel. In the *Philosophical Transactions* of 1735 it is reported that a tradesman named Wakefield "having put up a great number of knives and forks in a large box, and having placed the box in the corner of a large room, there happened, in July 1731, a sudden storm of thunder, lightning, etc., by which the corner of the room was damaged, the box split, and a good many knives and forks melted, the sheaths being untouched. The owner emptying the box upon a Counter where some Nails lay, the Persons who took up the knives that lay upon the Nails, observed that the knives took up the Nails." It was also known that thunderstorms have an effect upon the magnetic needle.

It was not until 1820, however, that a public description was given of the influence of an electric current upon a magnetic needle. Oerstead showed that if a wire carrying an electric current be placed

parallel to a magnetic needle, the needle is deflected. Thus a current of electricity in some way exerts a magnetic influence. A week after the news of this discovery reached the French Academy, Ampère, one of the greatest names in electrical science, showed that two parallel wires carrying electric currents attract each other if the currents are flowing in the same direction, but repel each other if the currents are flowing in opposite directions. Ampère, who was a superb mathematician, worked out a very fine mathematical theory explaining these effects.

In the year 1831 Michael Faraday revolutionized the whole science of electro-magnetism by his discovery of electro-magnetic induction. We have already spoken of the lines of force of a magnet. This conception of lines of force is one of the ideas we owe to Faraday. He pictured the space around an electrified or magnetized body as being in a state of strain. At every point of the surrounding space a force, due to the body, was acting. We can imagine curves drawn in this space, such that at every point the direction of a curve is in the direction of the electric or magnetic force at that point. These curves are Faraday's lines of force. We are to picture the whole space around a magnet, for instance, as being filled with these curves. This is called the magnetic *field*.

Now Faraday made the extremely important dis-

covery that when an electric conductor moves in a magnetic field, cutting across the magnetic lines of force, as it were, an electric current is created in the conductor. The current flows only as long as the cutting motion continues. By moving a wire in a magnetic field we can create an electric current in the wire. This is the basis of the immense developments in electric technology which have occurred since his time. A dynamo, for instance, consists essentially of a magnet and of a coil of wire rotating in the field of the magnet. The coil of wire rotates in such a way that it is continually cutting the lines of magnetic force, and therefore an electric current is continually being generated in the wire. This is the most efficient means known of producing electricity.

Instead of making a coil of wire pass through a magnetic field we could, of course, use a moving magnet and keep the coil of wire stationary. The essential thing is to create, with respect to the wire, a varying magnetic field. We may summarize the matter quite simply by saying that a varying magnetic field produces an electric field.

It is also true that a varying electric field produces a magnetic field. Let us imagine two electrically charged balls, placed near each other, one being charged with positive electricity and the other with negative electricity. An electric field will be

created round them. Now let us suppose that these charges are caused to alternate very rapidly. We shall find that the changing electric field creates also a magnetic field.

We see that a reciprocal relation exists between electricity and magnetism. This relation was given mathematical expression by James Clerk Maxwell. All these experiments are summed up in his equations, which show precisely how the electric and magnetic forces are connected with one another. Now a mathematical formulation is not only a compact and convenient way of summarizing what we already know. The great advantage of mathematical formulation is that it enables us to realize the implications of what we know. Maxwell's equations, when their implications were worked out, showed that when a change begins in an electric or magnetic field that change does not spread over the whole field *instantly*. In the case of the two electrified balls we have just mentioned, for instance, when the charges on the balls are reversed the electric field is changed. But those parts of the field which are near the balls change first, and those parts which are far off change later. Further, Maxwell was able to show that the changes run through the field like waves, and these waves, although invisible, have the same shape and other properties as light waves. The next step was to find the velocity

with which these waves move, and he found that their velocity is the same as the velocity of light. In fact, the only difference between these electro-magnetic waves and light waves is that light waves are shorter. Maxwell did not hesitate to conclude that light waves are short electro-magnetic waves. This is the famous electro-magnetic theory of light, the greatest discovery in physical science of the nineteenth century. If we are now asked the nature of light we reply that light consists of varying electric and magnetic forces propagated through space with the velocity of 186,000 miles per second.

Maxwell's theory had to wait twenty years before it was confirmed by experiment. The brilliant young German physicist, Hertz, succeeded in making an apparatus which produced very rapidly alternating electric charges, and he found that electro-magnetic effects from this apparatus were propagated through space with the velocity of light. He found that these disturbances were analogous to light waves, for they could be reflected and refracted like light. Other experiments showed also that they could be concentrated through large lenses—again like light.

It is now accepted that all forms of wave-radiation, radiant heat, light, X-rays, γ-rays, are all electro-magnetic disturbances. They differ in their

wave-lengths, but in their fundamental nature they are the same. But valuable and important as this conclusion is, recent researches show that it still leaves a great deal unsaid about the nature of radiation, as we shall now proceed to show.

SECTION V.—THE NEW OUTLOOK

THE NEW OUTLOOK

§ 1. Atoms of Radiation

We are accustomed to believe that some things are continuous, and that others are discontinuous. The atomic theory of matter provides us with a case of discontinuity. If we could see a piece of matter under a sufficiently high magnification we would see a number of discrete little particles more or less closely packed together. Still further magnification would show that these little particles are themselves systems of much smaller particles. An atom, on the electron theory, is nearly all empty space, this space being very sparsely populated by minute flying electric particles. If all the electrons in a man's body could be jammed together, leaving no empty spaces, then the whole body would reduce to a barely visible speck. All the rest is empty space.

But there are various things that we regard as essentially continuous. Time, for example. We measure time by seconds, but we do not imagine that there is any timeless gap between one second and the next. One instant of time merges into the next instant in a perfectly continuous manner. We

can imagine a second being split up into any number of smaller intervals. In some scientific measurements we talk of millionths of a second. But, however much we split up a second, we never encounter anything which is timeless. A second, or any other interval of time, is time all through, as it were. We regard the passage of a moving body, also, as continuous. When it describes a path in space, we assume that it has passed over all the intermediate points on that path. It would not be illogical, however, to suppose that the body progressed in sudden jumps. We could imagine the body being annihilated at a point and re-created a little farther on, again annihilated, and again created a little farther on, and so on. If the intervals were made short enough and the creation followed quickly enough on the annihilation we would not be able to distinguish between this and continuous motion. As we know, the moving pictures give the illusion of continuous action by some such process. Nevertheless, we do not believe that a moving body acts in that way. We believe that its motion is continuous.

Another thing that we naturally regard as continuous is energy. Consider, for example, the heat energy of a body. This becomes greater as the temperature of the body increases, and we can imagine this increase being as gradual as we like. We can talk of millionths of a degree as we can talk

of millionths of a second, and we can imagine smaller and smaller intervals without limit. We may not be able to observe such small changes of temperature in practice, but we have no doubt that, when we do observe a change, the body has not jumped to it suddenly, but has passed through all the intermediate stages. It is the same with increasing energy of motion, as when a fly-wheel rotates faster and faster, or a falling stone falls more and more swiftly. We believe that the energy increases in a continuous manner, and not by sudden jumps. It is therefore very interesting to know that modern science abandons this idea. It is now generally accepted that energy is atomic; it does not increase or decrease in a continuous manner, but by jumps.

This revolutionary idea was first put forward by Max Planck in the year 1900. He found it necessary to explain certain experiments that we shall describe, and it has since developed into the vast Quantum Theory, which applies to all the most intimate workings of nature.

We know that when we heat a body it begins to glow a dull red, and finally, if we raise its temperature high enough, it becomes white-hot. If we could raise the temperature still further we should find that the body acquired a bluish tinge. What happens is that the energy emitted by the body becomes of shorter wave-length as the body gets hotter. At the

beginning, before the body begins to glow, it is sending out wave-lengths so long that they are invisible. It then begins to send out the longest of the visible waves, the red waves, and glows with a red heat. As it gets still hotter, more and more of the short waves come into play until we get that mixture of colours that constitutes white light. Further heating would increase the proportion of the short waves, and the light would become more blue.

Now these results, although so familiar, could not be accounted for theoretically. According to theory there should be no such predominance of particular colours at particular temperatures. At all temperatures, according to theory, the great bulk of the energy emitted should pass into the shortest waves. Theory and experiment completely contradicted one another. The calculations were gone over very carefully, and the experiments were repeated. The contradiction remained.

Max Planck saw that this contradiction can be removed if we suppose that the vibrating atoms of the hot body do not emit energy continuously, but jerkily. We are to suppose that an atom sends out a train of waves, and then stops. After an interval it begins again, and sends out another train of waves, and again stops. We do not perceive this intermittence because the atoms are acting quite indepen-

dently, and in any piece of matter we can handle there are, of course, billions of atoms. This idea, when Planck worked it out, accounted with great exactitude for the experimental results. Energy is emitted, not continuously, but by discrete *quanta*, as they are called. We may call them atoms of energy. The size of the atoms of energy depends on the frequency of the light, that is, on its rate of vibration. The shorter the wave-length the higher the rate of vibration. We have already said that, for red light, four hundred million million waves enter our eye every second. This figure expresses the frequency of the light. For violet light, which has half the wave-length, the frequency is twice as much. An atom of violet light energy is twice as big as an atom of red light energy. An atom of X-ray energy is very much bigger still. Planck discovered that we can always find the size of the atom of energy that belongs to radiation of a known frequency by multiplying that frequency by a certain number called Planck's Constant. This number is very small indeed. It is 6.55×10^{-27}. It is usually denoted by the symbol "h." Whatever the radiation may be, whether long electro-magnetic waves or the exceedingly short γ-rays, in all cases we get the size of the energy atom of that radiation by multiplying its frequency by the quantity "h." We cannot say why this should be so. It happens to be

a fact about nature, but we can at present give no theoretical reason for it.

Planck's theory, that energy is emitted in "quanta," was so revolutionary at the time it was put forth that scientific men looked on it with considerable doubt. But as time went on it became evident that this theory not only explained the radiation from a hot body, but was required for a whole group of phenomena for which the orthodox theory could give no explanation. Let us consider first the very curious phenomenon called the "photo-electric effect."

If light is allowed to fall on a clean metallic surface, electrons are emitted from the surface. The impact of the light releases electrons from the metal. The velocity of these electrons can be measured, and the extraordinary fact is found that their velocity does not depend at all on the intensity of the light. Whether we use a very weak light or a very strong one, the electrons come off with the same velocity. The only difference is in the number of electrons emitted. The more intense the light the greater the number of electrons that are released. If, however, we use light of a shorter wave-length we find that the electrons come off with a greater velocity. We find that the velocity of the emitted electrons depends solely on the wave-length and not at all on the intensity of the light. If we have a very

weak source of light of short wave-length, electrons will be emitted with a higher velocity than if we use a very intense source of light of longer wave-length.

To see how very paradoxical a result this is, let us consider the whole process. X-rays are generated, as we have seen, by the sudden stoppage of electrons. The disturbance spreads out in all directions around the stopped electron, and naturally as it spreads out it gets weaker. After travelling some distance a part of this disturbance encounters a metal plate. It immediately projects from this plate an electron having the velocity of the original electron As Sir William Bragg has said: "It is as if one dropped a plank into the sea from a height of 100 feet, and found that the spreading ripple was able, after travelling 1,000 miles and becoming infinitesimal in comparison with the original amount, to act upon a wooden ship in such a way that a plank of that ship flew out of its place to a height of 100 feet." It is evident that the idea that light spreads out through space in the form of waves cannot possibly explain this result. We must suppose that the disturbance created by the stopped electron somehow reaches the metal plate as a compact little bullet. Yet, as we have seen, the compact little bullet idea cannot explain the phenomenon of the interference of light. We have to use both

theories, and yet, so far as we can see at present, they cannot be reconciled.

The idea that energy is atomic in constitution, although it still presents difficulties, evidently has a great deal to recommend it. Let us consider some more evidence.

We have spoken of the electrons in an atom revolving about the central nucleus. According to the accepted laws of electro-magnetism such an atom could only last for a very minute fraction of a second. According to this theory, the whole material universe ought to have vanished directly it was formed. For a revolving electron, according to the laws of electro-magnetism, radiates energy. The effect of this is to make it describe a continually decreasing orbit, and finally it would spiral down into the nucleus. Then the atom would vanish in a flash of radiation. The whole process would take less than a millionth of a second. In this dilemma we once more invoke the quantum theory.

Niels Bohr, a young Danish physicist, was the first to apply the quantum theory to the structure of the atom. His application amounted to saying that, within an atom, electrons can move only in certain definite orbits at certain definite distances from the nucleus. Further, in flat contradiction to orthodox electro-magnetic theory, he assumed that an electron, while rotating in an orbit, does not

radiate any energy at all. An electron only radiates energy when it jumps from one orbit to another. This jump is in the direction of the nucleus, from an outer to an inner orbit. The amount of energy radiated by the electron is a quantum. If the atom receives energy the effect is to cause an electron to jump outwards, from an inner to an outer orbit. To be accepted the energy must be presented as a quantum of the appropriate size. If either less or more than this is presented the atom merely ignores it.

This theory, when it was put forward, seemed to rest on purely arbitrary assumptions. No reasons, based on the known laws of nature, could be given for the behaviour attributed to electrons by this theory. Nevertheless, the theory turned out to be a great success. The wave-lengths of the radiation sent out by the jumping electrons could be calculated pretty completely for the simplest cases, namely, the atoms of hydrogen and helium. Now the spectra of these elements, as we have said, consist of lines corresponding to each particular wave-length emitted. When the positions of these lines were compared with those predicted by the theory, the agreement was found to be remarkably close. This was a great triumph, for the characteristic spacings of spectral lines had never been accounted for before. More precise investigations, however, showed that there

were discrepancies between prediction and observation, and it came to be recognized that the Bohr theory, in its original form, was unsatisfactory.

We need not pass in review the different attempts that were made to modify the theory, for in recent years an entirely new outlook on the whole subject has been developed. But we have mentioned Bohr's theory because certain fundamental features of it still remain. There was a truth, for instance, in his notion of special orbits, although that truth is now seen in a very different light. We no longer regard an electron in an atom as a little particle running round a particular orbit. The electron still preserves much of its particle character, but it has also become a wave. The new outlook is, in fact, described by the title, The Wave Theory of Matter.

§ 2. Waves of Matter

We have seen that radiant energy, whether visible light or any of the forms of invisible radiation, partakes of the character of corpuscles as well as of waves. In the photo-electric effect, radiation behaves like a flight of little bullets; in the interference experiment it behaves like a train of waves. We have to accept the fact that it is both. This is very puzzling, for we cannot imagine, on the basis of our experience of ordinary matter, what sort of thing radiation can be. But, indeed, the reader must be warned that the whole of this part of our subject entirely baffles the pictorial imagination. This is an embarrassing fact, not only for the layman, but also for the scientific worker, who usually likes to form mental pictures of the processes he is describing. It is possible that the root of the difficulty lies in our notions of space and time. If we are to picture anything we cannot avoid giving it a spatial content. We may picture its size and shape as continually varying, but we cannot help attaching the notions of size and shape to it. It seems that this mental habit, so far as modern science is con-

cerned, is misleading. Experiments with telescopes show, for instance, that a single quantum of light must be large enough to fill the lens of any telescope. The lens of the telescope at Mount Wilson is 8 feet 4 inches in diameter. The effect of this quantum on a photographic plate placed at the eye-piece of the telescope shows us that it is also small enough to enter an atom whose diameter is one hundred-millionth part of an inch. It is obviously impossible to picture such an entity. It seems reasonable to conclude that the notion of spatial extension does not apply to the quantum. In some mysterious way it transcends space. However that may be, we shall find that this kind of difficulty is frequently met with in the new conceptions.

We were used to regarding light as a wave. We find that it is also a sort of particle. We are used to regarding matter as particles. Is it possible that these particles are also waves? Experiments have been made, and we find that matter, like light, has the enigmatic characteristic of possessing both properties. When a narrow beam of X-rays is passed through a metal and allowed to fall on a photographic plate held at right angles to the beam we find that a pattern of concentric circles is formed on the plate. This phenomenon can only be produced by a wave motion, and the sizes of the circles enable us to calculate the length of the X-ray waves.

Professor G. P. Thomson has performed a similar experiment with electrons. Electrons, compared with X-rays, have but slight penetrating power, and sheets of metal through which X-rays pass can stop electrons completely. Professor Thomson succeeded in making gold-leaf less than a millionth of an inch thick, and through this he was able to pass electrons. It was found that these electrons, when they fall upon a photographic plate, form a pattern of concentric rings, exactly similar to those produced by X-rays. Here is a proof, therefore, that electrons are waves. Other experiments show just as indubitably that electrons are particles. A theory has been worked out which tries to combine these two aspects of matter, but this theory is, at present, not only in a highly technical state, but it does not yet seem to be completely understood, even by its creators. An electron is represented in this theory as being associated with a series of waves, but these waves are not physical waves. They seem to be as immaterial as the waves of loyalty, sorrow, etc., which, at certain times, sweep over a country. They cannot be represented as existing in some medium in space. Such success as the theory has achieved shows that this representation does correspond to something that exists in nature. But of the something that is represented in this way we at present know nothing. For our purposes, therefore, we must

be content with the statement that radiation and matter possess both wave properties and corpuscular properties. Before we can combine these facts in an intelligible manner we shall probably have to revise our notions of space and time. A certain revision of our notions has already been affected by Relativity Theory, but this revision apparently does not go far enough. Certainly relativity theory does not explain quantum phenomena. Nevertheless, relativity theory covers an extremely wide range. In fact, we may say that it covers everything but quantum phenomena. Modern physics may be regarded, roughly, as falling into two parts, and at present there is not much connection between them. Phenomena on a minute scale are covered by quantum theory. Phenomena on the grand scale are covered by relativity theory. We now turn to consider this latter group of phenomena.

§ 3. Relativity

It was in 1905 that Albert Einstein, then working in the Patent Office at Berne, published his first paper on what has come to be called relativity theory. The term is not altogether a happy one. The layman often thinks that the theory preaches that everything is relative, that all fixed standards have been dissolved away, that everything has been shown to be dependent on the point of view. Certainly the theory showed that certain things we had always thought of as fixed are not fixed. For instance, the distance between two points is not a fixed thing. The time between two events is not a fixed thing. But, on the other hand, the theory discovered certain things that are fixed—really fixed. And its demonstration that certain things are absolute is just as valuable, and just as much a part of the theory, as its demonstration that certain things are relative.

Relative to what? The answer at first seems a strange one. Relative to *motion*. Einstein's first paper may be summarized as answering the question: "What difference does an observer's motion make to his scientific observations?" We have already

said that people playing billiards on a uniformly moving train would notice no difference whatever in the behaviour of the billiard balls. Nor would they notice any difference in any other mechanical phenomena. Pendulums, for instance, would swing at the same rate. If we have a number of systems, all moving with uniform motions with respect to one another, then the observers on these different systems would find all mechanical phenomena going on in exactly the same way, and would therefore reach the same set of mechanical laws. But would they find the same set of laws for other phenomena, such phenomena, for instance, as light and electricity? At first sight it seems that they would not.

To make the principle involved clearer, let us consider the motion of a ship across a still lake. If the ship is moving steadily, no mechanical experiments within the ship made by the passengers will reveal the fact that they are moving. But suppose they make experiments which involve the lake, which is not taking part in their motion. Then they will discover that, with reference to the lake, they are moving. A stone dropped from the side of the ship, for instance, will set up ripples in the lake. But these ripples will not seem to spread out as they would do if observed from a stationary ship. The ripples will seem to be spreading astern faster than they are spreading forward. In fact, if the passengers

had not known they were moving, this experiment would immediately reveal their motion to them. Similarly, if we cause light ripples to spread out in the ether, it does not seem that they would appear the same to an observer in motion as they would to a stationary observer. But we do not have to bother about carrying out this experiment on a moving train, for we have a much faster moving body in the earth itself. The earth, in its yearly motion round the sun, is moving through whatever medium it is that supports light-waves, and by flashing light rays in different directions we ought to be able to detect this motion. The experiment has been tried several times, but in every case the light ripples spread out just as if the earth were stationary. This is not because the difference is too small to be measured. The apparatus used was so delicate that even one hundredth part of the effect expected could have been measured. Yet in no case was the slightest difference ever found.

The correct interpretation of this extraordinary fact was given by Einstein. He enunciated it as a principle that scientific phenomena are not altered in any way when they take place in different systems which are in uniform motion with respect to one another. The motion of the observer, provided it is uniform, makes no difference to any of the phenomena with which science is concerned. Connected

with this statement is another which is, at first sight, much more extraordinary. That is the statement that the velocity of light is the same for every observer, whatever his motion. We see how extraordinary a statement this is if we try to apply it to any moving object with which we are familiar, such as a motor car or a rifle bullet. The rate at which any object passes us obviously varies according to whether we are advancing towards it, receding from it, or are standing still. But in the case of light, Einstein asserts that our motion makes no difference at all. Whether we are advancing towards the light, or are receding from it, we always find that its measured velocity is 186,000 miles per second. Einstein was led to this statement by the fact, as we have already mentioned, that the earth's motion round the sun makes no difference to the observed speed of light, whether the light be sent in the direction of the earth's motion or in any other direction.

In order to understand how deep-lying are the implications of the statement that the velocity of light is the same for observers in relative motion, we must bring out clearly the paradox of the statement. Suppose we are at rest and that we are passed by an observer travelling with half the velocity of light, that is, at the rate of 93,000 miles per second. We send a ray of light after him, which we observe

to overtake him at the rate of 93,000 miles per second. Our statement asserts that this observer, when he measures the velocity at which this ray is overtaking him, finds it to be 186,000 miles per second. The fact that he is running away from the light does not subtract from its measured velocity. Similarly, if he were advancing towards the light, nothing would be added to its measured velocity. That would still be 186,000 miles per second.

Now these statements are so opposed to common sense that they sound like sheer nonsense. If they are to be accepted it can only be after a radical revision of some of our most fundamental assumptions. Einstein proposes such a revision. He points out that the above statements become quite sensible if we suppose that an observer's measuring instruments change with his motion. To find a velocity, we have to measure a distance and also a time. Einstein says that these measurements change in such a way with an observer's motion that he always gets the same value for the velocity of light. He says, in fact, that distance and time are not absolute things, but are relative to the motion of the observer. If a penny is presented to us flat-on it looks round. Presented edge-on it looks a straight line. From any other angle it looks an ellipse. The shape of the penny is relative to the point of view. In this case we say that there is a " real shape " to the penny.

We say that the penny is really round. That is, we distinguish the observer who looks at the penny flat-on above all other observers, and say that he only has got at the truth of the matter. Our reasons for this preference are a matter of argument amongst philosophers, but we have no doubt, in practice, that our preference is justified. But we cannot do this sort of thing with our moving observers. We have no grounds whatever on which we can single one out above all the others. For rest and motion are relative terms, as we have seen. We cannot, for instance, pick on one observer and say that he is absolutely at rest. We have no criterion at all for absolute rest. All observers in uniform motion with respect to one another are on the same footing. In this case we have nothing corresponding to the roundness of the penny, which we all agree to be the only true shape. The point is that motion, like the shape of a penny, depends on the point of view. But whereas with a penny we single out one shape (the circular one) as being the *true* shape, we have no means whatever of doing this with motion.

We may point out that there is nothing "psychological" about these changes of space and time measurements with motion. They would be recorded by automatic recording machines, just as a camera would record the changes in shape of a penny.

We see that the experimental failure to detect any variation in the velocity of light when sent in different directions on a moving earth is responsible, in Einstein's hands, for some very startling conclusions. If the whole purpose of his theory was to explain the negative result of this experiment, it might be thought to be cracking a nut with a steam hammer. But the theory, when worked out, makes so many other things clear that the scientific world has now accepted it.

If we are to regard space and time measurements as relative, then we must be living in a universe very different from the universe we thought we were living in. Space and time cannot be the completely separate entities we thought they were. They must be connected in some way, and the distinction we make between them must be, to some extent, illusory. This fact was brought out very clearly by Minkowski, some three years after Einstein's first paper appeared. He showed that the reality lying behind appearance is a continuum having four dimensions. Each observer splits this continuum up into three dimensions of space and one dimension of time. The way in which he effects this partition depends on his motion. All observers with the same motion live in the same space and time. An observer having a different motion lives in a different space and time. These different spaces and times are

cross-sections, as it were, of the one four-dimensional reality.

The great importance of this point of view is that it brings out the *absolute* features of Einstein's theory. Everything that refers directly to the four-dimensional continuum is absolute, that is, is the same for all observers. There is, for instance, a quantity called the *interval* which is the same for all observers. Suppose we have two events—say, two flashes of light. They are, we suppose, distant from one another, and they occur at different times. Different observers will disagree about both these factors. But if they combine their measurements in a certain way they will all reach the same result. This particular combination of space and time measurements is called the interval. It is a sort of mixture of space and time, and it refers directly to the four-dimensional continuum.

One very interesting fact that comes out of this theory is that the mass of a body increases as its velocity increases. At ordinary speeds this increase is not perceptible, but at speeds approaching the speed of light it becomes very apparent. At nine-tenths the velocity of light, for instance, a body's mass is about two and a half times greater than its value at rest. At 99 per cent. of the velocity of light it is seven times greater. The particles shot out by radium move sufficiently fast for us to test this

theory. We find that the increase in mass does occur in accordance with Einstein's formula. Einstein's formula again shows us the peculiar position occupied by the velocity of light, for it says that at the velocity of light the mass of a body would become infinitely great. To make it move faster, therefore, would require an infinitely great force. This formula can only mean, therefore, that the velocity of light is a sort of limiting velocity in our universe. Nothing can possibly exceed this velocity. In fact, it seems to play the part that we naturally attribute to a strictly infinite velocity. We agree that adding or subtracting any finite speed to an infinite velocity does not affect it. We have seen that the same holds good for the velocity of light. Again, nothing can surpass an infinite velocity. The same is true of the velocity of light. Also, if we went into the mathematics of Einstein's theory we should find that we cannot add velocities together in the usual straightforward way. They do not combine according to the laws of arithmetic. Each added velocity produces less and less effect, as it were, and in such a way that the sum total can never exceed the velocity of light. This again is like an infinite velocity, for however many velocities we add together, even in the ordinary arithmetical way, we can never exceed infinity. On Einstein's theory it appears that we live in a universe so strangely

constituted that the velocity of light plays the part of an infinite velocity.

Another interesting result of Einstein's theory is the identification of mass and energy. We have said that the mass of a body increases with its motion. We also know that a body in motion has more energy than that body at rest. It has more energy in virtue of its motion, and the faster a body moves the greater is its energy of motion. These two facts are not unconnected. The increase in mass is, indeed, due to the increase in energy. Energy and mass, we find, are convertible terms. If we heat a body we increase its energy, and by doing so we increase its mass. A body radiating heat or light or any other form of radiant energy is losing mass. It has been experimentally demonstrated that light exerts pressure on any object on which it falls. This pressure is due to the momentum of the moving light energy. Like a water jet, a jet of light exerts pressure because it has mass. But the mass of a quantity of energy is, relative to our ordinary standards of measurement, very small. The mass of the light sent out by a powerful searchlight, shining continually for a century, would amount only to a minute fraction of an ounce.

A body radiating energy is transforming part of its mass into energy. It is theoretically possible for its whole mass to be transformed into energy,

although we cannot yet accomplish this feat in our laboratories. The amount of energy that could be obtained in this way is really stupendous. It far surpasses any other source of energy known. If one gram of matter could be changed into energy it would furnish 9×10^{20} ergs. This is more than two hundred thousand million times as much energy as would be given out by one gram of water in cooling from boiling-point to freezing-point. A piece of matter the size of a pea, if transformed into energy, would suffice to drive the *Mauretania* across the Atlantic. We cannot yet avail ourselves of this source of energy, but there is some evidence that the stars are doing so. There is good evidence to show that the stars have existed for a period of millions of millions of years. They have been radiating energy all that time. The question naturally arises: "Where does the energy come from?" The only theory that seems adequate to explain the facts is the theory that the stars are transforming their matter into radiation. This could conceivably come about by the coalescence of protons and electrons. If a proton and an electron united they would both vanish in an intense flash of radiation. We may suppose that this occurs in the central regions of the stars, where they have temperatures of several millions of degrees. The radiation so produced would be of exceedingly short wave-length, but it

can be shown that these waves, on their journey up from the centre through the mass of the star, would become lengthened, and reach us in the forms we know.

The transformation of a single pound of any substance into energy would give as much energy as the burning of five million tons of coal, yet, even so, the sun is losing mass at the rate of 360,000 million tons every day. That is the actual weight of the energy emitted by the sun daily. That is the fact, whatever theory we invoke to account for it. A reasonable theory, as we have säid, is that the sun is transforming its matter into energy. On the other hand, it may be that the sun acquires its energy by some such process as building up helium atoms out of hydrogen. We have seen that that process is attended by the liberation of a considerable amount of energy. But whatever the source of the energy, we know, by calculating the sun's total radiation from the fraction of it that falls on our earth, that the actual mass of the radiation emitted by the sun daily is 360,000 million tons. Yet so enormous is the mass of the sun that it could go on losing mass at this rate for another fifteen million million years.

To sum up what we have learnt so far from the theory of relativity. We have learnt that mass and energy are convertible terms, that the velocity of

light is a critical velocity in our universe, and that space and time are aspects of a four-dimensional continuum. Ten years after his first paper Einstein published a great extension of his theory. This extension is called the Generalized Theory of Relativity, the first theory being known as the Special Theory of Relativity. The general theory bestows a greater unification upon the phenomena of nature than has ever been reached before.

§ 4. General Relativity

The difficulty that has been haunting us through all these last pages, namely, the non-picturability of modern scientific theories, becomes very grave when we come to consider the general theory of relativity. Here we must frankly trust our reason and be content to let our pictorial imagination lag hopelessly behind.

We have said that Minkowski pointed out that Einstein's first theory amounted to saying that space and time are merely aspects of a four-dimensional continuum. The space and time that an observer explores with his measuring instruments changes when the observer's motion changes. But behind these changing aspects is the four-dimensional continuum, which remains one and the same. We cannot apprehend this continuum directly. Our minds and senses are so constituted that we are, as it were, at one remove from reality. The most immediate and fundamental things in our direct experience of the external world are space and time —aspects of the reality which lies behind them, and which we cannot reach except through them. It is

only by analysing our space and time experiences that we can learn anything about the reality which includes them both.

The scientific data from which we learn about the four-dimensional continuum are our spatial measurements and our time measurements. We study the behaviour of our measuring rods and clocks. From their observed behaviour we have decided that their indications vary when their motions vary, and vary in such a way that the velocity of light, when measured by them, always turns out to be the same. Their variations are therefore not at random; they are connected together by a definite law. In a mathematical exposition we should, of course, give this law, but for our present purposes that is unnecessary.

From the behaviour of measuring rods and clocks we deduce the metrical properties of the four dimensional continuum—what is called its geometry. It used to be thought that there was only one possible geometry for any continuum, namely, Euclid's geometry. But during the last hundred years mathematicians have shown that any number of other geometries are possible. It is not true that measuring rods and clocks *must* obey the laws of Euclid's geometry. Minkowski showed that the four-dimensional continuum revealed by Einstein's special theory is not Euclidean. Its metrical

properties do very largely obey the laws of Euclid's geometry, but there are discrepancies. And these discrepancies lead to the results we have already described, the constancy of the velocity of light, the relativity of space and time measurements, and so on. All these curious results testify to the fact that we live in a non-Euclidean universe.

But we are not limited to the observed behaviour of measuring rods and clocks for our knowledge of the metrical properties of the continuum. We can learn a great deal, for instance, by observing the motion of a freely moving body, that is, a body not subject to impacts of any kind. Now the planets are not subject to impacts. They describe, as we know, nearly circular orbits about the sun, and this has been attributed to a gravitational force. But Einstein, in his generalized theory, developed quite a different way of looking at the matter. To understand this let us consider how the notion of a gravitational force arose.

Newton assumed, as was universally assumed at his time, and for many years later, that the metrical properties of space must obey the laws of Euclid's geometry. In that case the motion of a freely moving body, not subject to impacts, is motion in a straight line. Now the planets are not subject to impacts; nevertheless they do not move in straight lines. There must therefore be some force, Newton

concluded, pulling them out of the straight-line path. He found that he could account for the motions of the planets if he supposed this force to be a gravitational pull between the sun and the planets. Thus we see that the notion of a gravitational force arose because Newton took it for granted that the natural, unhampered motion of a body is motion in a straight line.

Einstein questioned this assumption. He was familiar, as Newton was not, with the fact that Euclid's is not the only possible geometry. Further, Minkowski had shown him that space is not a self-sufficient entity, as it were, and that what was really involved was a mixture of space and time, a four-dimensional continuum. Minkowski had already attributed a certain geometry to this continuum, and this geometry, as we have said, differed somewhat from Euclid's. But it was like Euclid's geometry in this respect, that the natural unhampered motion of a body was still motion in a straight line. Thus the force of gravitation was still necessary to account for the motions of the planets. Einstein wondered whether, by attributing to the continuum some entirely different geometry, the force of gravitation could be shown to be unnecessary. He wondered, in fact, whether the continuum had such metrical properties that the observed motions of the planets were natural, unhampered motions, requiring no

force of gravitation to explain them. It so happened that the great German geometer, Riemann, had invented a geometry according to which the unhampered motion of a body would be very different from motion in a Euclidean straight line. Einstein adopted this geometry and applied it to the four-dimensional continuum. He found that the planets would move, according to this geometry, just as they are observed to move. Also, he found that all the laws of mechanics are necessary consequences of this geometry. And the fact that mass and energy is conserved, that is, that any loss of the one is balanced by the gain of the other, was also found to be a necessary consequence of this geometry.

Thus a great region of natural phenomena was illuminated. What had been regarded as a number of special laws of nature, requiring special forces and properties to explain them, were seen to be necessary consequences of the structure of the four-dimensional continuum. Various phenomena which had been regarded as separate and independent were seen to be necessarily linked together. Thus a great unification of nature was effected.

The unification was not complete. Mechanics and gravitation had been accounted for, but electromagnetism still remained outside the scheme. All forms of radiant energy, as we have seen, come under the heading of electro-magnetism, and they

form a very important part of physical phenomena. It was felt to be a serious drawback, therefore, that nothing in the structure of the four-dimensional continuum, so far as that structure had been worked out, could account for them. These electro-magnetic forces appeared purely as extras ; Einstein's theory left them just as inexplicable as they had ever been. Further, it could be shown that Riemann's geometry, adopted by Einstein, could not possibly account for them. All the resources of that geometry had already been used up, as it were, in accounting for gravitation and mechanics. The only way of pursuing the path opened up by Einstein was to attribute a still more complicated geometry to the four-dimensional continuum.

Attempts have been made, by Einstein amongst others, but it cannot yet be said that any of these attempts have gained universal acceptance. The precise manner in which the electro-magnetic forces enter into the general scheme is still in doubt.

A greater measure of success has attended another effort of Einstein's genius—his theory that the universe is finite. By this he does not mean only that there is finite amount of matter in the universe, although that also is true, but he asserts that the actual volume of space is finite. Here again we have a statement which, at first sight, seems to be nonsensical. But in saying that a statement is non-

sensical we must ask ourselves whether we are saying that it is logically self-contradictory, or whether we are merely saying that it is non-picturable. The one does not imply the other. The space of Einstein's theory has no boundaries, but at the same time it is not unlimited. This statement is not self-contradictory. We can illustrate the idea involved by an analogy, if we confine our attention to a space having only two dimensions, namely, length and breadth. Such a space is called a surface, and we know that we can have two main kinds of surfaces—plane and curved. If we consider a plane surface, such as the surface of a table, then obviously it cannot be without boundaries unless it is also unlimited. The only way a table can avoid having edges is by being infinitely big. But the same thing is not true of the surface of a sphere. Neglecting such practical obstacles as seas and mountains, a man could travel about on the surface of the earth for ever without ever leaving the surface. If he followed his nose and went straight ahead he would never encounter a boundary, although he would ultimately arrive back at the place he started from. The surface of the earth is a two-dimensional space which is finite, but at the same time it has no boundaries.

The usefulness of this analogy is that it enables us to realize that the words "unlimited" and "unbounded" do not mean the same thing. We see

that the surface of a sphere is *intrinsically* different from the surface of a table. It can be both finite and unbounded, and this combination of properties is quite impossible for a plane surface. Now the mathematicians have worked out that three-dimensional spaces also can be of these two kinds. It is possible for three-dimensional space to be analogous to a plane surface. Such a space cannot be unbounded unless it is also unlimited. This is the kind of space that we have always supposed ourselves to be living in. But it is also possible for a three-dimensional space to be analogous to a spherical surface. Such a space can be finite and unbounded. Einstein gave reason to suppose that our space is of this kind. It is quite impossible for us to picture this kind of space. But we can reason out how measuring rods and clocks, moving bodies, rays of light, and so on, would behave in a space of this kind, and we can compare this behaviour with the behaviour we actually observe. The evidence that we live in a finite space, although not overwhelming, has been found sufficiently convincing by the majority of scientific men who concern themselves with the matter.

Nowadays this theory has taken a new turn. The idea has been put forward that this finite space is continually expanding. Here, as elsewhere in this theory, we are in the region of the unpicturable, but

the statement has a perfectly common-sense significance which we can illustrate by an example. In Einstein's finite universe a ray of light would go on for ever, but it could only do so by continually coming round again to its starting-point, very much as a man could go round and round the earth. The actual distance that would be traversed in one such circumambulation could be approximately calculated. It was, of course, many millions of light-years. The theory of expanding space asserts that this distance is continually growing greater. Indeed, it is supposed that the universe is now growing so fast that a ray of light would never complete the journey. The circumference of the universe, as it were, is lengthening faster than light can move, and so the farther the ray of light goes the farther it has to go.

This extraordinary theory rests primarily on certain mathematical considerations. It can be shown that the original finite universe, postulated by Einstein, is unstable. It must either contract or expand. The evidence we have shows that the universe is expanding.

We know from observation that the matter of the universe is collected into separate systems which are far removed from one another. These separate systems have been called "island universes." They are also called "spiral nebulæ," because they present

a more or less developed spiral form when seen through the telescope. The magnitude of these systems is stupendous. A recent estimate declares that each spiral nebula, on the average, contains one hundred thousand million stars. It is also computed that the total number of such systems in the universe is in the neighbourhood of the same figure, namely, one hundred thousand million. Each of these systems is, as it were, self-contained, separated one from the other by vast empty spaces that light would take millions of years to traverse.

Now the extraordinary fact has been established that practically all these systems whose motions have been measured are moving away from us. There are a few exceptions, but it is probable that these are only apparent, and that, when the proper corrections have been made, these also will be found to be receding from us. On the ordinary theory there is no explanation for this. If the motions of these systems were entirely at random we would expect to find as many approaching us as are receding from us. But according to the theory of an expanding universe this phenomenon is just what we should expect. Further, the theory states that those systems which are comparatively near to us should be receding more slowly than those which are farther off. In fact, the farther away a nebula is, the faster it should be receding. This, also,

is confirmed by observation. We find that the nebulæ obey just this law. The most distant nebula whose motion has been measured is situated one hundred and fifty million light-years from us, and this is receding with a velocity of fifteen thousand miles per second.

Thus observation supports the theory of an expanding universe, and, as we have said, there are very weighty mathematical arguments in favour of it. Nevertheless, the theory introduces a great difficulty into the scientific outlook. We have already said that there is good reason to believe that the stars are millions of millions of years old. We deduce this from various considerations that we need not go into here. But the theory of an expanding universe will not admit of anything like such a time-scale. The universe must have expanded from an initial condition when it was much more compact. We cannot go back indefinitely; there is a limit to this process. And the calculations show that this limit is reached long before we have gone back for millions of millions of years. Indeed, some estimates are less even than the age we have attributed to the earth. We have seen that there is good reason to suppose that the earth is not less than two thousand million years old. But the whole universe is not as old as this, according to some estimates based on the theory of an expanding universe. It must be

admitted, therefore, that the theory is not yet in a very satisfactory state. We have thought it well to acquaint the reader with this very interesting speculation, but it cannot yet be definitely put forward as one of the doctrines of modern science.

Recent Advances in Atomic Theory

We have hitherto described the atom as made up of two primary constituents—protons and electrons. An electron is charged with negative electricity. A proton carries an equal charge of positive electricity. Also, a proton is about 1,830 times more massive than an electron. We have also seen that the helium nucleus, consisting of four protons and two electrons, may also be regarded as a sort of unit owing to its great stability. It enters as a unit into the composition of the nuclei of many atoms. Recently two other constituents of the atom have been found—the neutron and the positron. The neutron has a mass about the same as that of a proton, but it manifests no electric charge. It passes through a collection of atoms without being diverted from its path by their attractions. For this reason it has great penetrating power. It is thought that a neutron consists of a proton very closely connected with an electron. We may imagine, for instance, that the electron is rotating round the proton at a very small distance from it. They would thus each mask one another's electrical action. It is supposed that, with a neu-

tron, the revolving electron is tens of thousands of times nearer to the proton than is the revolving electron in a hydrogen atom. The bond of connection, owing to this smaller distance, would be very much stronger. We have to regard the neutron as a very stable structure. The other constituent that has recently been discovered, the positron, is a sort of positive electron. It has the same mass as the electron, but it carries a positive charge of the same magnitude as the negative charge of the electron. We must now say a little more about the atom in the light of these and other discoveries.

In the year 1919 it occurred to Rutherford to bombard atoms with the α-particles shot out by radium. He knew that it is only by altering the nucleus of an atom that it can be changed into the atom of another element. The nucleus of an atom is, however, very stable and well protected. The circulating electrons of an atom can be disarranged or detached by X-rays, or even feebler radiations, but these have no effect on the nucleus. The α-particles of radium, however, convey much more energy. An α-particle, fired directly at the nucleus of an atom, might well be able to penetrate its defences. Such a direct hit could not be ensured, of course, but if a sufficient number of α-particles were fired off there would be a chance that some of them would score direct hits. Rutherford began

by bombarding oxygen, but in this case nothing in particular happened. When he bombarded nitrogen, however, he found that protons wêre shot out of the nitrogen atoms. Careful experiment has made clear the mechanism of this process. The α-particle actually enters the nucleus of the nitrogen atom and causes a sort of explosion there. This explosion causes a proton to be shot out.

We can understand the details of this process better if we first examine the structure of the nitrogen nucleus. We know that the nuclei of all atoms except hydrogen (whose nucleus consists simply of one proton) contain both protons and electrons, with the protons predominating. The number of uncompensated protons in the nucleus of an atom is given to us by the "atomic number" of that kind of atom. Thus the nucleus of a helium atom consists of four protons and two electrons. There are here two uncompensated protons, and the atomic number of helium is two. The "atomic weight" of an atom, we have seen, is equal to the number of protons it contains. Thus the atomic weight of helium is four. Now consider nitrogen. Its atomic number is seven, and its atomic weight fourteen. Its nucleus, therefore, contains fourteen protons, of which seven are uncompensated. There are, therefore, seven electrons in its nucleus. Now, how are we to consider these fourteen protons and seven electrons to

be arranged? A group of four protons and two electrons, as we have seen, is able to arrange itself in a very stable sfructure, as in the case of the helium nucleus. Three such groups could form themselves in the nitrogen nucleus. These three groups would account for twelve protons and six electrons. We are left with two protons and one electron. This is not a particularly stable combination, and, as we find experimentally, an α-particle is sufficient to disrupt it, with the result that a proton is shot out.

Helium, carbon, oxygen, and many other elements, cannot be disrupted by α-particles. This is not surprising in the case of the helium nucleus (which is of the same constitution as an α-particle) owing to its immense stability. Carbon, with an atomic number of six, and an atomic weight of twelve, has a nucleus just equal to three helium nuclei. Oxygen, atomic number eight, and atomic weight sixteen, has a nucleus equal to four helium nuclei. The energy of motion of an α-particle is not sufficient to disrupt such structures.

When nitrogen is disrupted by an α-particle, the protons shot out soon capture an electron, and hydrogen is formed. What happens to the α-particle? It becomes embedded in the nucleus of the atom it has struck. A new atom is thereby produced. The nucleus of this new atom contains four helium nuclei, together with one proton and one electron.

Its atomic number is therefore eight. But this is the atomic number of oxygen. So that the nitrogen atom, after liberating hydrogen, has been transformed into an atom of oxygen. It is true that the atomic weight is higher than that usually given for oxygen, being seventeen instead of sixteen, but w have already seen that isotopes exist that is, atom of the same element but of different eights. Thi new atom is an isotope of oxygen. It was found late that small quantities of this isotope are present in ordinary oxygen. For every 12,500 oxygen atoms of weight sixteen there is one oxygen atom of weight seventeen.

A number of the lighter elements can be transformed in this way, that is, by bombardment with α-particles. Of course, very few of the α-particles that are fired off score a hit, since the target they are aimed at is so very small. In the case of nitrogen only about one particle in one hundred thousand hits a nucleus. For aluminium the proportion is even smaller, being about one in a million.

An entirely new phenomenon was observed when the element beryllium was bombarded. No protons could be detected, but nevertheless a very penetrating radiation of some kind was emitted. It was found that this radiation consisted of particles having about the same mass as a proton, and carrying no electric charge. They were named neutrons.

A beryllium atom is of atomic number four, and atomic weight nine. We may suppose, therefore, that its nucleus contains two helium nuclei, together with one proton and one electron. It is supposed that the proton and electron are united together to form a neutron, and this is ejected under α-particle bombardment. The α-particle enters the nucleus of the beryllium atom, thus transforming it into an atom containing three α-particles. This atom is carbon. Other elements, besides beryllium, also shoot out neutrons under bombardment. It is probable that neutrons occur frequently in the structure of atoms. The addition of a neutron to the nucleus of an atom does nothing to change the character of the atom, since it does not alter its positive charge. It merely alters its atomic weight. It is thought, therefore, that isotopes are atoms that differ from one another only in the number of neutrons they contain.

α-particles are produced, of course, by the spontaneous break-up of radium. Recently, however, a technique has been developed whereby very fast protons can be produced artificially. An electric discharge passed through hydrogen will strip the atoms of their circulating electrons. The remaining protons can then be given great velocities by subjecting them to a sufficiently intense electric field. Electric fields of the order of a million volts have been successfully constructed for this purpose.

When these high-speed protons strike on lithium atoms, for example, it is found that helium nuclei are shot out. This is remarkable, for the lithium atom cannot be disintegrated by α-particles, which actually have more energy than the fast protons used in this experiment. A proton, by penetrating into the nucleus, evidently causes a sort of explosion there. There are two isotopes of lithium, of weights six and seven. The isotope of weight seven is the more abundant, and it is this isotope alone that is concerned in the phenomena. Its nucleus consists of a helium nucleus plus three protons and two electrons. We see that the addition of another proton would enable a second helium nucleus to be formed. It appears that this is what happens, and, in some way we do not yet understand in detail, this happening is attended with a vast release of energy, the two helium nuclei being projected from the atom in opposite directions with immense energy. The energy of these projected helium nuclei is something like a hundred times that of the proton that caused the explosion. In some cases, indeed, the exploding atom gives out five hundred times the energy it received. But it must be remembered that only one proton in a thousand million succeeds in causing the lithium atom to explode. Still other elements have been found to break up in this way under proton bombardment.

Besides the proton, yet another particle has been used recently in these bombardment experiments. This is the newly discovered isotope of hydrogen, of mass 2. There is one atom of this "heavy hydrogen," as it is called, to every six thousand atoms of ordinary hydrogen, of mass 1. The nucleus of this heavy atom has been given great speeds by applying very intense electric fields, and it has been found more effective than ordinary protons in many cases. It breaks up lithium, but in this case it is the isotope of mass 6 that is involved. The helium nuclei are shot out with tremendous energy, with a greater energy, indeed, than is possessed by any of the α-particles shot out by radio-active substances. Many other elements can also be broken up in this way, with the emission of helium nuclei, and sometimes, very fast protons.

The existence of the positron, that is, the positively charged electron, was predicted on theoretical grounds, but it has only recently been discovered experimentally. As we have said, it has the same mass and charge as a negative electron, except that its charge is of the opposite sign. These positive electrons last for a very short time. Almost immediately they appear they combine in some way with a negative electron, with the result that both vanish, a flash of radiation taking their place.

These new entities—the positron, the neutron,

and the nucleus of the heavy hydrogen atom—have only recently been discovered, and not much is yet known about them. The nucleus of the heavy hydrogen atom has the same electric charge as the proton, but twice the mass. A water molecule, as we know, is a combination of two atoms of hydrogen and one atom of oxygen. A certain percentage of water, it has been found, has heavy hydrogen atoms entering into its constitution. This "heavy water" can be separated from ordinary water by distillation Its density is about 10 per cent. higher than that of ordinary water, and both its boiling-point and freezing-point are rather higher, its boiling-point being 101.4° C., and its freezing-point 3.8° C. Certain forms of animal and plant life, which flourish in ordinary water, are killed when immersed in this heavy water. The precise part it plays in biological processes is now being investigated.

THE END OF THE MATERIAL UNIVERSE

WE have seen in an earlier chapter that the heat possessed by a body, whether that body be solid, liquid, or gaseous, consists in the motions of the constituent particles of that body. These motions are quite chaotic. In a solid, liquid, or gas, the particles do not move according to any plan. In a solid or liquid the motions are much more restricted than in a gas, but they are just as indiscriminate.

Heat is a form of energy, and other forms of energy can be converted into heat energy. When a falling stone strikes the ground, for instance, its energy of motion disappears at the moment of impact, but the stone and the ground immediately around it have become warmer. The energy of motion has been changed into heat energy. The heat caused by the sudden stoppage of a rifle bullet is sometimes sufficient to melt the bullet. In such cases the essential thing that happens is that an orderly motion is changed into the disorderly, chaotic motion that constitutes heat. No energy has been lost; it has been transformed. Now heat energy, as we know, has a constant tendency to

dissipate itself and to become less available for doing useful work. Bodies at different temperatures have a tendency to reach finally one uniform level of temperature, and from bodies at the same temperature we cannot extract any useful work. A steam-engine cannot function when every part of it is at the same temperature. All the bodies in the universe have a tendency to reach the same temperature. Heat is continually passing from hotter bodies to cooler ones. That is to say, the heat energy of the universe has a constant tendency to reach one dead level, and to become thereby unavailable, since all interchanges of heat would then be impossible.

Other forms of energy also tend to change into heat energy. By doing so they become more chaotic and therefore less available. Let us consider, for instance, a swinging pendulum. We know that the pendulum, which possesses energy of motion, will ultimately come to rest. What has happened to its energy? The pendulum has been brought to rest by two causes—the friction of the supports, and the resistance of the air. Through each of these causes the energy of motion of the pendulum has been changed into heat energy. The friction has made the supports warmer, and this heat is gradually radiated away. The moving pendulum bob has struck some of the molecules of the air and thus

increased their velocity; it has made a portion of the air warmer. By successive collisions this increased molecular velocity is gradually transferred through the mass of air. In these ways the energy of the pendulum has become less available. Finally, indeed, it is dissipated throughout space.

Consider, again, a bended bow. When we release the string the energy of the strained bow is communicated to the flying arrow. Sooner or later the arrow comes to rest, and, where it strikes, heat energy is generated, and this energy is gradually radiated away.

In none of these processes is there any loss of energy, but the energy has become less available for doing work.

If we follow out the history of energy transformations we find that there is a general tendency for energy to assume a less available form. This tendency, so far as we know, prevails throughout the whole universe. We may say that the energy of the universe, although it never becomes less in amount, becomes steadily more and more disorganized and chaotic. This tendency has received mathematical expression. The mathematicians have succeeded in defining a quantity, called Entropy, which expresses the degree of disorganization suffered by energy in any transformation. And one of the most important laws in science, the Second Law of Ther-

modynamics, is to the effect that the entropy of the universe is continually increasing. This process cannot go on for ever. There must come a time when the entropy of the universe reaches its greatest possible value. No interchanges or transformations of energy will then be possible. In such a universe there could be no new beginnings of any kind, and no form of life could exist. Such a state represents, in fact, the final death of the physical universe.

BOOK II

SECTION I.—THE FUNDAMENTAL UNITS OF LIFE

THE FUNDAMENTAL UNITS OF LIFE

§ 1. Life's Variety

We have seen that all the substances which make up the material world can be reduced to ninety-two separate elements. Of these ninety-two elements only ninety are actually known, so that the other two must be exceedingly scarce. And of those known many occur only in very minute quantities. It is possible that the interiors of the stars contain elements that do not exist on earth, but, so far, we have not encountered such elements by direct observation. Analysis of the light that reaches us from the stars shows no elements with which we are not familiar.

The most plentiful element in the universe seems to be hydrogen, for the stars are chiefly composed of it. On the surface of the earth the most plentiful element is oxygen. Inorganic nature, if we confine ourselves to the earth's crust, contains a greater percentage of oxygen than of any other element. Oxygen is also one of the chief ingredients of organic substance, that is, of the substances that occur in living bodies.

The number of chemical elements that occur in

living bodies is relatively small, but the complication of their compounds is far greater than anything that is to be found in inorganic nature. Chief among the elements making up the matter of living bodies are carbon, hydrogen, oxygen, and nitrogen. A dozen or more other elements are also found, but in smaller quantities. In the living body the substances formed by these elements are extremely complex, and very sensitive to external influences. Temperatures well below the boiling-point of water are usually sufficient to destroy life, although some seeds and spores can survive a temperature of 120° C. and more. Certain lowly organisms can endure a rather greater range of temperature downwards, however. Bacteria and the spores of fungi have been kept for days at a time at the temperature of liquid air and have still remained alive. Certain animals living in moss have even survived the temperature of liquid helium, which is only four degrees above the absolute zero.

Animals and plants are the two main divisions of living things. In most cases it is easy enough to tell them apart. But there are a few cases where our ordinary criteria fail us. We cannot say, for example, that all animals move about and that plants do not. Some animals, as sea-squirts, are rooted at one spot, and some plants are mobile. The really essential difference between plants and animals

is in their food. Plants can obtain the elements necessary to their existence directly from the air and water in which they live. Animals cannot make use of these elements directly; they have to be presented to them in highly organized forms. These highly organized forms are, indeed, built up by the plants. Animals are, in the long run, entirely dependent upon green plants. Green plants, in their turn, cannot make use of their food without the aid of the sun's rays. The sun's energy is indispensable to the chemical food processes of plants. Thus all forms of life depend, ultimately, upon the energy of the sun.

The sheer variety of living things is one of the most amazing facts about them. Here Nature exhibits a variety of resource, and what seems like a prodigality of imagination that is altogether beyond human possibilities. In mere size, for instance, the range is stupendous. A single drop of water would be large enough to contain about three hundred millions of the creature called the malarial parasite. At the other extreme we have the sulphur-bottomed whale, which reaches a length of nearly 100 feet, and weighs 150 tons. Some plants are even larger. A big tree of California may reach a size ten times that of the largest whale. Besides their variations in size, we know also that living things differ enormously in all other respects—in colour, shape, habits,

etc., etc. As might be expected, therefore, it is no easy task to classify so great a diversity of creatures.

As a matter of fact, no completely definite classification can be given. Even the division into animals and plants is not perfect, for there are creatures which possess both characteristics, being able to build up their food from simple inorganic substances like a plant, and also to deal with complex compounds like an animal. Nevertheless, the biologists have worked out a system of classification of all known animals and plants which covers satisfactorily practically the whole field. The whole animal world is built on relatively few main structural plans. Thus, animals apparently so different as a man and a frog are built on the same ground plan, and are included in the same great division of Vertebrata. The lobster, on the other hand, is constructed in a radically different way, and is assigned by the biologist to another of the great main divisions. Such creatures as the snail and cuttlefish, again, belong to yet another main division. There are about a dozen such great divisions altogether. Within these main divisions we find that certain subdivisions suggest themselves. These subdivisions are again divided, and so on. The final term in this process of subdivision is the *species*. Animals belonging to the same species have the greatest practical degree of likeness. For the purposes of the classificatory

biologist, individuals belonging to the same species are indistinguishable. We could only carry the analysis further by considering the varieties within a species, and, finally, each individual animal.

And yet this notion of species is not perfectly definite. It is not always possible to say whether a particular animal belongs to one species or to some neighbouring species. No criterion which has yet been proposed for the demarcation of species is obeyed with absolute strictness throughout the animal kingdom. This fact fits in with the modern idea that species are not fixed things, separately created, but spring from a common stock. In fact, modern speculations go so far as to suppose that every form of life, animal and vegetable, has sprung by modifications extending over many millions of years, from some primitive seed of life. In spite of the immense difference between, say, a starfish and a man, it is supposed that, if we go far enough back, we shall find that they and all other forms of life had a common ancestor. We shall see later that there is very considerable evidence for this point of view, but we shall start by considering a great basic fact—the cell-structure of living matter.

§ 2. The Basic Form of Life

It was not until about the middle of the seventeenth century that reasonably good microscopes were made, and by using these Malpighi and Grew discovered that plants are composed of a number of little structures they called "cells." These cells look like tiny little boxes fitted closely together. In the living plant these boxes contain a slimy substance called protoplasm. It came to be recognized that it is the contents, and not the boxes themselves, that are the really important element in the structure of plants. *In speaking of the cell structure of plants, therefore, we now refer to these protoplasmic contents, and not to the skeletal boxes.* With this changed meaning the word "cell" is, it must be admitted, not very appropriate. It arose merely as an historical accident. It is even less appropriate when it is applied to the structure of animals, for here the "cells" are without cell-walls, and may even be mobile little bodies of various shapes and sizes.

A cell is usually a flat, rounded body of microscopic size. There are plenty of exceptions to this rule. Cells may be spherical, cube-shaped, star-

shaped, or thin threads. And some are very far from being microscopic. But we may confine ourselves, at present, to the normal form. A cell is composed of a semi-fluid, almost wholly transparent substance of chemical composition so complicated that it is not yet thoroughly understood. In most cases the cell is enclosed in a cell-membrane, which regulates the passage of materials in and out of the cell. Somewhere about the centre is usually a round object called the nucleus, also enclosed in a definite membrane of its own. The surrounding substance of the cell is called the cytoplasm. This, when examined closely, is seen to be of very complicated structure, containing granules, thin threads, and globules of oil, these constituents being in movement.

The cell may be taken as the irreducible, ultimate form of life. All higher organisms are built up out of cells. But a cell, although relatively so simple a thing, can preserve an independent existence. Cells can be taken from various parts of an organism and preserved alive indefinitely in suitable media. Indeed, there are certain organisms, leading an independent existence, which seem to consist of nothing but a single cell. Such organisms are called unicellular. A celebrated example is the amœba, which can be found in the greenish scum that accumulates at the bottom of ponds, etc.

This creature is microscopic in size, and seems to

consist of just a blob of protoplasm, except for the fact that it contains a nucleus. Besides the nucleus can be seen another globule called the contractile vacuole, which periodically swells and bursts, and then re-forms. This is a device for getting rid of the water which is continually seeping into the amœba. But beyond these structures the amœba has no organs such as we usually associate with an animal. Nevertheless, the amœba moves about, it devours and digests food, it breathes in oxygen and breathes out carbon dioxide, and it reproduces itself. It moves by extending lobes of itself, and then, as it were, flowing into these lobes. It feeds by wrapping itself round the microscopic plants, etc., that form its food, it digests what it finds nourishing in this food, and it then flows away from the waste products. It takes in its oxygen and gives out its carbon dioxide from any part of its surface. But perhaps its most amazing characteristic is to be found in its method of reproducing itself. It accomplishes this by separating itself into two halves, each of which grows into a complete individual. It is essential that the nucleus take part in this process so that it is equally divided between the two products. Each of these halves, on reaching maturity, splits up into two individuals which in turn split up, and so on. Thus the actual substance of an amœba never dies. It lives on distributed

throughout its offspring. Some of these creatures divide up every hour. If we started with one amœba, and it were allowed to proliferate undisturbed, then in a few hours a pond would be one mass of amœba from top to bottom. In a week the mass of amœba derived from a single individual would be many times the mass of the whole earth.

Can we attribute consciousness to the amœba? Certainly its actions are analogous to those we describe as conscious in ourselves and the higher animals. It responds to variations in light intensity, for example, by definite behaviour. It seems to have the power of voluntary movement. Also, it chooses its food. It does not devour everything indiscriminately; it takes no notice of indigestible grains of hard mineral, for instance. Our natural tendency is to interpret behaviour of this kind as being conscious behaviour. It is not impossible, nevertheless, to maintain that such behaviour is mechanical in the sense that it is the outcome purely of the laws of physics and chemistry. Mechanical models can be made which simulate, more or less, the behaviour of an amœba. If drops of chloroform are put into a suitable liquid they will remain suspended, and, on approaching small grains of sealing-wax they will engulf them very much as an amœba engulfs its food. Also, by taking advantage of certain chemical reactions, the phenomenon of cell-division that

occurs when an amœba reproduces itself can be, to some extent, imitated. Nobody suggests, however, that these models explain the amœba's behaviour. The laws that explain these models certainly do not explain the amœba. All that these models do is to make us surmise that a mechanical explanation of the amœba is possible.

The possibility remains very slight, however. The chemical compounds that go to form a living cell are so complex that chemists have hardly yet begun to understand them. And the arrangement of these compounds within the cell, their mutual actions and reactions, and the way they conspire to maintain the amœba as an individual whole—all this is still a complete mystery. There are plenty of biologists who maintain that the origin, structure, and behaviour of a living cell cannot be explained by the laws of physics and chemistry. There are other biologists who hold, as an article of faith, that a mechanical explanation of life will one day be given. So far as science has gone at present, however, a mechanical explanation of life has not been even approached.

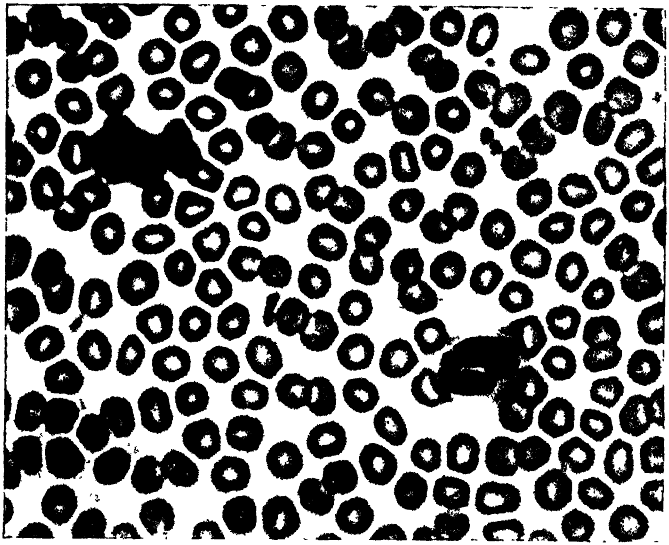
There are even smaller organisms than single cells. There are, for instance, the bacteria, which may be hundreds or even thousands of times smaller than microscopic cells. These little creatures are not differentiated into parts. There is nothing

corresponding to the nucleus of the ordinary cell, for instance. They seem to be homogeneous throughout. They reproduce themselves by the simple device of splitting in half, and they multiply very rapidly. An ordinary bacterium lives for about twenty minutes before dividing. We see that, if allowed to flourish undisturbed, they would multiply far more rapidly even than amœba.

Bacteria, as we know, cause many diseases, but they also perform a number of useful functions. They are important in agriculture, for instance, for there are bacteria which transform the nitrogen of the air into substances that plants can deal with. Hoofed animals and other plant-eaters could not digest grass except for the aid of the bacteria that live in the digestive canal. Also, bacteria, by producing putrefaction and decay, enable the chemical substances of dead bodies to come into circulation again. There are many species of bacteria, of different sizes and shapes, and they exist in great abundance everywhere—in earth, air, and water. Usually they can be killed immediately by raising them to the temperature of boiling water; but bacteria, as a sort of protective device, can assume the form of spores, that is, little particles of living matter enclosed in a resistant shell, and in this form they are much harder to kill. They can survive the temperature of boiling water for hours, and that of liquid air for months.

Bacteria are the smallest creatures that can be seen, even with the best microscopes, but we have good evidence that still smaller creatures exist. This discovery was first made in connection with that notorious scourge, foot-and-mouth disease. Suppose we take some of the fluid from one of the sore blisters that appear on the lips and hoofs of an animal suffering from this disease. Now suppose we pass this fluid through a very close-grained substance, such as fine porcelain. Porcelain may be regarded as a very fine filter. It will let the molecules of the liquid through, but it will not allow any bacteria, visible under the microscope, to pass. Nevertheless, the fluid which has passed through a porcelain filter will infect another animal with foot-and-mouth disease. Further, the fluid from this second animal can be used to infect a third animal, and so on. The disease does not get weaker as it is transferred from one beast to another. It is evidently due to something which, though invisible, can multiply and proliferate like a bacterium. These creatures are called "filter-passing organisms." Several species of them are known, each one producing its own particular kind of disease. The common cold is thought to be produced by these organisms.

There is evidence of the existence of a still smaller something called bacteriophage, which preys on and destroys bacteria. We call it a "something,"



The cells are of two kinds, red and white, of which the red are much the more numerous. Together with the red cells, two white cells are seen in the above photograph.

because there is controversy as to whether it is actually a living creature. It manifests some of the properties of life, but it is sometimes regarded as a sort of link between living and non-living matter. It is estimated that a bacteriophage is so minute that it does not contain more than about a thousand molecules.

Apart from this world of microscopic and ultra-microscopic creatures, the standard form of life is the cellular form. All higher organisms are built up of cells. Skin, bone, nerve, muscle, etc., etc., are all built up out of cells. And these cells, of different shapes, sizes, and functions, are all co-ordinated to serve the purposes of the body as a whole. But a complicated living body, such as the human body, is not composed wholly of living cells. The cells of gristle and bone, for example, secrete dead substances out of themselves, and thus build up the skeleton or framework. An account of the various cells of the body and of the way in which they are co-ordinated would be equivalent to a treatise on physiology, but we may here say something about a very important group of cells—the blood cells.

Blood is for the most part water which contains a great variety of chemical substances. But about a third of the total volume of our blood is composed of cells—the red and the white cells. Of these the red cells are by far the more numerous, there being about six hundred red cells to every white cell. It is

the red cells that give our blood its distinctive colour, due to the presence in the red cells of a red pigment known as *hæmoglobin*. These red cells seem to be remarkably homogeneous. They contain no nucleus. In shape they are bi-concave discs, being thinner in the middle than at the edge. They are large enough to be seen by a quite ordinary microscope, and they are exceedingly numerous. The human body contains about twenty million million of them. Their chief function is to carry the necessary oxygen supplies throughout the body. The white cells are somewhat larger, they possess nuclei, and some of them are capable of independent movement. There are some half-dozen varieties of them, each with its own functions. These functions are protective. It is the white cells that attack the parasites and disease germs that invade the body.

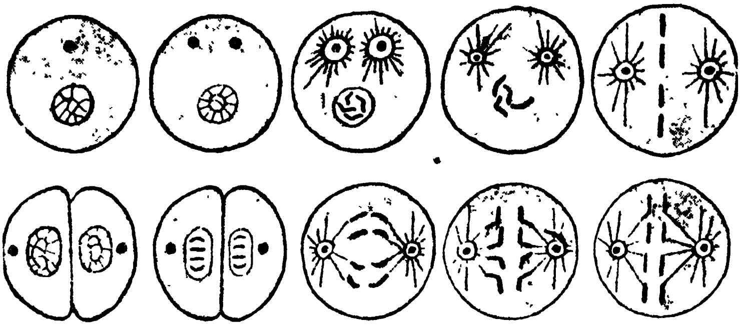
Human beings, and, indeed, all higher organisms, are built up, as we have said, out of cells of various types, according to the purposes, muscular, nervous, and so on, that the cells are required to serve. The growth in size of any part of the body is due to the multiplication of its constituent cells. Thus a man is really a huge colony of cells, each kind of cell performing its own proper functions, and yet, in obedience to a most marvellous discipline and order, working in co-ordination with all the other cells to serve the purposes of the body as a whole.

§ 3. How Life Develops

Nearly all living things spring, in the first place, from a single cell. This single cell divides, and produces two cells. Each of these cells in turn divides, and so on. This process of cell division, when examined in detail, is seen to be exceedingly remarkable. It proceeds in stages. In the first place the contents of the nucleus change from their fluid state into a number of little rod-shaped bodies, and the wall of the nucleus breaks down. These little rod-shaped bodies are called chromosomes. Also, a star-shaped body, with radiating fibres, appears in the cell and presently splits into two. Now the chromosomes arrange themselves in a line between these two bodies, the radiating fibres of which attach themselves to the chromosomes. Each chromosome divides in half, lengthwise, and the two halves separate from one another, as if they were being pulled apart by the radiating fibres attached to them. The cell now divides down the space left between the divided chromosomes. Thus each half-cell has a complete set of half-chromosomes.

(See diagram.) The half-chromosomes collect together in each case to form a new nucleus, and we are left finally with two cells each of exactly the same constitution as the original cell.

By this process of repeated division most living things are built up. But the cells which go to form one animal must obviously differ from the cells which go to form some entirely different anima



Illustrating the phenomena of cell-division. See Text.

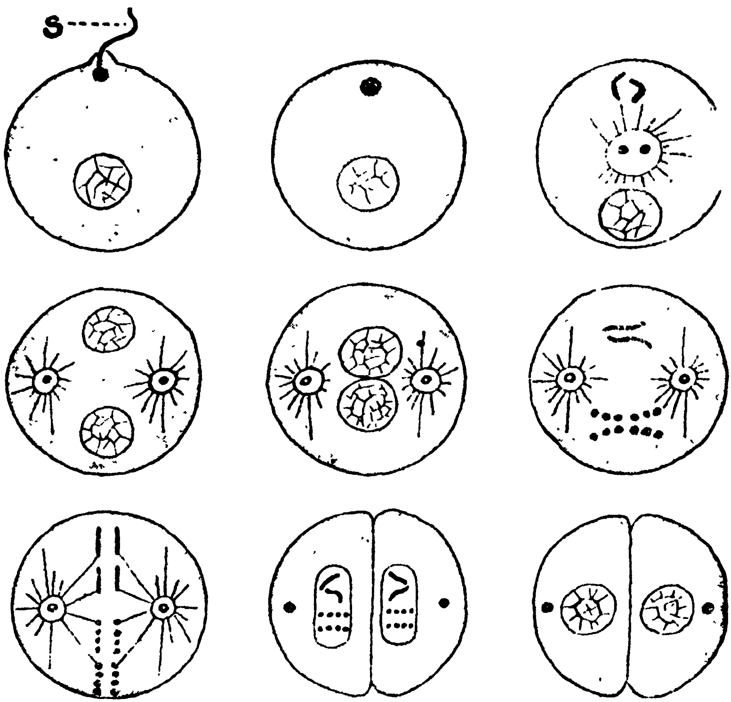
These differences are supposed to reside in the chromosomes. Chromosomes do, in fact, differ in size and shape. Also, the cells of different animals often possess different numbers of chromosomes. The cells that constitute the human body, for instance, each contain forty-eight chromosomes. With some creatures each cell contains scores of chromosomes, with others there are only two or three in each cell. But the cells of the same race

of animals or plants always contain the same number of chromosomes.

The cell out of which a living thing develops nearly always comes, in the first place, from the fusion of two cells, one contributed by the male and the other by the female. This is true of most plants, and of all the higher animals. The cells that play this rôle differ from all the other cells that constitute the organism. They possess only half the number of chromosomes, for instance. To distinguish these cells from the others they are given a special name. They are called gametes, while the other cells are called zygotes. The process of the formation of gametes is, of course, different from that of zygotes. Two gametes are formed from a cell containing the full stock of chromosomes characteristic of that animal, whatever it may be; but, in the process of division, the chromosomes do not split in half. They remain quite whole, but half of them go to one daughter cell and half to the other. Thus, in the case of human beings, a cell containing forty-eight chromosomes, if it is destined to form gametes, splits into two cells each containing twenty-four chromosomes.

When the male and female gametes, called respectively spermatozoon and ovum, unite, they merge together to produce a cell containing the normal number of chromosomes, and this cell, by dividing

in the ordinary way, produces finally all the cells that build up the body of the new animal. This is the method of sexual reproduction, and is the method



Illustrating the phenomena of cell-division. See Text.

adopted by most living creatures. A gamete from the male unites with a gamete from the female to produce the new creature.

We have seen that a very primitive, single-celled creature, such as amœba, multiplies by ordinary cell division, that is to say, the chromosomes split in half, so that each daughter cell contains the same number of chromosomes as the parent cell. Bacteria, as we have seen, multiply by merely dividing in halves. With such primitive creatures there is no such thing as male and female. The division into male and female, and the method of sexual reproduction, is evidently something that developed after the most primitive stage was passed. These special cells, the gametes, are stored in special parts of the bodies of all males and females, and it is only when a gamete from the female unites with a gamete from the male that a new creature can originate.

It used to be thought that some small living things arise "spontaneously." It was noticed that a swarm of little creatures can be found in, for instance, putrefying meat. It was thought that the process of putrefaction somehow gives rise to these creatures. But it is found that when proper precautions are taken to keep the meat clear from floating spores, etc., in the air, then no life develops in it. It is now established that in every case we can observe life comes from pre-existing life. This fact makes the origin of life on this planet a mystery, for it seems to say that life must always have existed. And yet we know that the early conditions of tem-

perature, etc., on earth, must have made all life impossible. In this dilemma most biologists assume that life did, in the first place, arise spontaneously. They assume that certain combinations of inorganic substances occurred which then manifested the properties of life. But as there is no experimental evidence for this, it remains at present an article of faith. The alternative is to suppose that life reached our planet in the form of "germs" wandering through space. We may suppose that these "germs" came originally from some other planet on which life has developed. But to say this only pushes the mystery one stage further back. We still have to explain the origin of life on the other planet. To make the theory plausible we have to suppose that these germs have always been present—that life is as old as matter itself. It is difficult to believe that, in the conditions of interstellar space, living germs can continue to float about indefinitely. One is more or less forced to conclude, therefore, that life has arisen from non-living matter, although the hypothesis seems, in many ways, an unlikely one, and we have no vestige of experimental evidence for it.

§ 4. Inheritance

We have said that the characteristics of an animal depend in some way on the chromosomes that inhabit the cells of which it is composed. Experiments have shown that the factors which determine the characteristics of a creature are contained within the chromosomes of its cells. These factors are called genes, and there are a number of them in each chromosome. Genes are too small to be seen, and therefore their existence cannot be confirmed by direct observation. Their existence, like that of atoms, is deduced from a number of experiments. It is sometimes the case that one gene is responsible for one characteristic, but this is by no means always true. It would not be correct to say that all genes are completely independent of one another, one gene being responsible for eye-colour, another for shape of wings, etc., etc. Things are not always as simple as that. Sometimes a characteristic is produced by several genes conspiring together. But, whether singly or in groups, the genes are the fundamental units of inheritance.

The first man to discover the laws of inheritance

was the Austrian abbot Mendel. His work passed unnoticed for several years, his results were then rediscovered, and since then a great deal of work has been done on the subject. These results can be best expressed in terms of the modern discovery of chromosomes.

The ordinary zygote cell contains an even number of chromosomes. When the zygote is about to divide to form two gametes the chromosomes arrange themselves in pairs, and, in the process of division, one half of them goes to one gamete and one half to the other. These two gametes, formed from the same zygote, may therefore differ in their chromosome outfits. Consider, for instance, a pink flower *which is formed* by crossing a red and a white. The colour of this flower is the result of the operation of two colour factors, one red and one white, inherited from its parents. Each of its zygotes, containing a full stock of chromosomes, contains both a red and a white factor. But when the zygote divides to form two gametes we find that its chromosomes separate into two groups in such a way that the white factor goes to one gamete and the red to the other. Now these gametes are waiting to be fertilized, that is, each gamete is waiting to be combined with a gamete from another individual. Suppose these other gametes come from another pink flower. Then one of these gametes will possess a white factor, and the

other a red factor. It is quite easy to see what the possibilities are here. We may have two white-factor gametes combining, or two red-factor gametes combining, or we may have the white of the one combining with the red of the other. This last case is really two cases, for we may have the red of the first flower combining with the white of the second, or we may have the white of the first flower combining with the red of the second. The two cases produce the same result, of course, namely, a pink flower. The other two cases produce, one, a red flower, and the other a white flower. Thus we see that the pink flower is not a *blend* between the white and red flowers that produced it. In the cells out of which it is built, the zygotes, it contains both factors, the red and the white. They do not blend, but exist intact side by side.

The zygotes of a pink flower, as we have seen, contain one red unit and one white unit. In a red flower there are two red units, and in a white flower two white units. The two gametes derived from a zygote of a red flower must therefore each contain a red-producing unit. And similarly for the gametes of a white flower. Knowing this, we can say what the possibilities are, when, for instance, a red flower is crossed with a pink flower. We see that the results must be either red or pink. If inheritance were a matter of blending, we should not expect this result.

We should expect that the crossing of a pink and a red would produce a darker shade of pink.

So far we have been talking merely of the factors which produce colour. But the same general rule holds good, whatever factor we are considering, that is to say, inheritance does not occur in accordance with the rules of blending. And all the different factors, responsible for all the different characteristics of the living creature, work independently of one another. For instance, a plant, besides possessing colour factors, may also possess height factors. Besides red and white units it may possess short and tall units. We find that these two groups of units act quite independently of one another. Its colour *has no influence on its* height. Both the tall and short plants can be of either colour. If we take a large number of factors into account, as we must do, of course, with any actual organism, then the number of variations we can get is obviously very great. Nevertheless, it would not be true to say that every possible variety occurs in nature. It sometimes happens that two or more of the genes behave as if they were linked together. It happens, with some species of organisms, that certain characteristics always appear together. But, with these exceptions, it is true in the broad sense that the various characteristics of an animal or of a plant are inherited independently of one another.

It would be too much to say that *everything* that is inherited comes from the genes. There is some evidence that the cytoplasm of the cell is also concerned—in some cases, at any rate. But the influence of this seems to be relatively slight. By far the greater part of the make-up of any creature can be traced to the genes. This probably holds good of mental, as well as of physical, characteristics. In cases where mental characteristics can be clearly distinguished, as, for example, musical ability in human beings, statistics show that they obey the laws of Mendelian inheritance.

So far we have discussed the laws of inheritance as if every heritable characteristic had equal weight, as it were. We have assumed that each gene produces its full effect. Thus we have said that the result of crossing a white flower with a red flower is a pink flower. The white unit and the red unit, we have said, play an equal part. Now this is by no means always true. It often happens that one unit overpowers the other. It is quite possible, for instance, for a brown-eyed person to contain one brown unit and one blue unit. The blue unit is masked by the brown unit. A person cannot be blue-eyed unless both units are blue. Thus two blue-eyed parents cannot produce a brown-eyed child, for there is no brown unit for the child to select. But it is quite possible for two brown-eyed

parents to produce a blue-eyed child. For suppose that neither parent possesses two brown units. Then each parent possesses both a brown and a blue unit. It is therefore possible for the child to have inherited a blue unit from each parent, and therefore to be blue-eyed. A unit which masks another unit in this way is called a *dominant* unit. The other unit is called *recessive.*

Mendel's original experiments were carried out with two varieties of peas, talls and dwarfs. The result of crossing these two varieties was to produce a new generation composed exclusively of talls. But the result of interbreeding between these talls was to produce both talls and dwarfs. The theory of dominant and recessive units explains this.

The talls which resulted from the original cross each contained a tall unit and a dwarf unit, but the tall unit was dominant to the dwarf. By inbreeding between these some offspring would select the dwarf unit from each parent, and so would be dwarfs. Of the other offspring, some would be true talls, possessing two tall units, and the rest would be hybrid talls, possessing one tall and one dwarf unit.

In speaking of dominant and recessive factors we must mention that the distinction between them is not always completely hard and fast. The recessive unit is not always completely masked by the presence of the dominant unit. It may appear in a compara-

tively feeble and fragmentary form. Thus it may happen, for instance, that a recessive colour is not completely swamped by the dominant colour, but appears fragmentarily as spots or detached markings. Dominant and recessive are terms which admit of degrees.

We have seen that the genes, hypothetical submicroscopic bodies located in the chromosomes, are the unit factors of heredity. A change in the genes leads to the inheritance of new characteristics. Such changes do occur spontaneously in nature. They are called mutations. A mutation may be recessive or dominant. If it is recessive it may take some time to manifest itself, for it is only when two animals having the same mutation mate that the offspring will have a chance of manifesting the new characteristic. Until then the mutation will lie dormant. Albinism, for instance, seems to be due to a mutation which is recessive. Two parents, neither of whom appear to be albinos, may give birth to a pure albino child. Mutations which are dominant manifest themselves, of course, from the first.

If a mutation, especially a dominant mutation, gives the creature an advantage over its competitors, or in any other way makes it easier for it to get a living, it will tend to become established. In time the creatures with this mutation will tend to supplant those who do not possess it. In this respect,

therefore, the species will have changed. If, therefore, mutations are sufficiently frequent, we see that, in the course of time, very great changes could be produced in this way. Mutations are, in fact, the material with which evolution works. Mutations are continually occurring throughout the world of living things, and the theory of evolution maintains, as we shall see later, that these mutations are responsible for all the variety of living creatures that inhabit, or have inhabited, the earth.

Of recent years it has been found that mutations can be produced artificially. Numbers of the fruit fly, *Drosophila melangoaster*, have been bombarded by X-rays, and, as a result, some hundreds of mutations have been produced. The bombarded fruit fly does not itself undergo any visible change, but it proceeds to breed fruit flies which exhibit new characteristics. It appears that the genes in the gamete cells carried by the fruit fly are directly affected by these rays. The offspring of these bombarded flies differ from the normal in such things as eye-colour, size of wings, etc. The changes so produced are permanent. The offspring of these transformed flies inherit the new characteristics in accordance with the ordinary Mendelian laws. Some of the mutations so produced are dominant, and some are recessive. Some of them are known mutations; that is, mutations that have previously been observed

to arise in fruit flies in the course of nature, and some of them are entirely new.

In some cases mutations can be brought about by chemical means. By feeding certain caterpillars on food containing lead and manganese, a new type of moth has been created. Instead of turning into light-coloured moths, as they normally would, these caterpillars turn into dark-coloured moths. This change, also, is permanent, and is transmitted according to the laws of Mendelian inheritance, even without the aid of the special food.

Such changes must be rigorously distinguished from changes that are not inheritable. It sometimes happens that, by changing the environment, very marked changes in the plant or animal can be produced. The Chinese primrose, for instance, blooms both in a red and in a white variety. If the red variety be kept in a hothouse at a very high temperature, it is possible to obtain a white instead of a red flower. But if normal conditions are restored, the red flower again appears. The change produced in this way is not a permanent, inheritable change.

Besides temperature, other external influences, such as moisture and illumination, can be used to produce marked changes in certain organisms. Insects, in particular, can be made to undergo great changes by suitable treatment. Most biologists are agreed, however, that no clear case has yet been

brought forward to show that such changes are inheritable. It appears that such changes are confined to the body cells of the organism, and are without effect on the reproductive cells. And unless the reproductive cells are affected, the change is not inheritable. We may sum this up by saying that *acquired characteristics are not inherited.* Whatever bodily or mental characteristics we may acquire for instance, are not handed on to our children whether those characteristics be good or bad. Exercise may develop our own muscular power, but it will not cause our children to be born with bigger muscles. Our industry in learning foreign languages will not make born linguists of our children. And such weaknesses and vices as we may acquire have no tendency to be inherited. Of course, we must distinguish between what is merely acquired and what comes from a natural predisposition, and in practice this is not always easy. A knowledge of languages may come partly from industry and partly from a "gift." The gift may well be inheritable, but the results of industry will not be inheritable. The results of muscular exercise will not be inherited, but the natural tendency to grow big muscles may very well be inheritable.

The distinction between acquired and inborn characteristics is, we see, very important. Lamarck, the great French zoologist, published the theory,

about a hundred years ago, that personal striving on the part of the organism could lead to changes that were inheritable. Thus he imagined that giraffes, by stretching upwards to the higher branches of trees in times of food scarcity, gradually developed longer and longer necks. Each giraffe lengthened his neck a little, and handed on the result to his descendant. There are still biologists who are sympathetic to Lamarck's general outlook, but the great majority do not accept it. We may take it as a very probable, although not yet completely demonstrated, biological doctrine, that acquired characteristics are not inherited.

If all living creatures have evolved from more primitive forms we must assume that this has occurred through changes in the genes. We do not yet know the cause of those changes. As we have seen, they can, to some extent, be produced artificially by the use of X-rays. We also know that waves of short wave-length are continually reaching the earth from outer space. It may be that these rays cause the mutations that take place in nature. But that, at present, is a mere speculation. We believe that mutations are the raw material of evolution, and that mutations come about through changes in the genes, but we cannot yet say anything definite about the causes of these changes.

SECTION II.—EVOLUTION

EVOLUTION

§ 1. Kinds of Living Things

We have seen that practically all living things, animals and plants (neglecting for the moment such lowly organisms as bacteria, etc.), have the great common characteristic that they are built up out of cells. Further, the great majority of living things reproduce by sexual union. This is not universal. We have seen that single cells can reproduce merely by division. Also, it can happen that, before division, two cells fuse together, and that these two cells are of the same kind. There is here nothing corresponding to male and female. Such cases occur, however, only with very lowly forms of life. Of nearly all organisms it is true to say that they are built up of cells, and that they reproduce by sexual union.

Apart from these basic resemblances the main characteristic of the world of living things seems to be its amazing diversity. But we have already said that biologists have classified the animal world into about twelve main divisions, and that these divisions have been further subdivided. The great main divisions are called phyla, and all the creatures that

belong to any one phylum are constructed on the same ground plan. The most important of these phyla, the one that contains all the most highly organized animals, is the vertebrates.

The most prominent members of the great group of vertebrates are fishes, amphibians, reptiles, birds, and mammals. There is here obviously an immense variety, and yet all these creatures are constructed on one fundamental plan. Between a fish and a man, for instance, there are great similarities. Each has a skull and a backbone, a brain and a spinal cord, a heart, stomach, kidneys, liver, spleen, etc., etc. Also, the paired fins of a fish are homologous to the limbs of a man or other mammal. In an amphibian, such as the frog, we find still closer resemblances, to fish on the one hand, and to mammals on the other. Indeed, we know that the frog spends the early part of his life as a very fish-like creature. The young frog, in the tadpole stage, has no limbs, and breathes, like a fish, through gills. It later develops lungs, and also limbs, complete with hands and feet. Amphibians form, as it were, a connecting link between water animals and land animals. Between birds and mammals, also, there are very strong resemblances when we come to compare them carefully. And birds and mammals are the only creatures that are warm-blooded.

A full account of the resemblances that exist

between the various animals called vertebrates would fill a large book. They are all constructed on one fundamental plan, variously modified according as the creature lives in water, on the land, or in the air. This fact leads one to surmise whether all the vertebrates might not have had a common ancestor. We can imagine some early form of vertebrate from which all these various animals have descended.

Each of the other great phyla are also characterized by a fundamental plan. We may consider, for example, the Arthropoda phylum. This includes an immense number and variety of creatures, such as lobsters, crabs, shrimps, spiders, scorpions, butterflies, beetles, ants, earwigs, centipedes, etc., etc. The fundamental construction of all these creatures is utterly different from that of the vertebrates. Their skeleton is exterior, and consists of segments. Appendages, each consisting of a number of hinged joints, are attached to these segments. These appendages play various rôles. Some have become sense organs, some are used for walking or swimming, and some are feeding organs. Besides these differences from vertebrates, we find that arthropods are blue-blooded creatures, and that their nervous system is quite differently placed, running along the lower side. All their internal organs, also, are profoundly different. The lobster, for example, has teeth in its stomach, it has no spleen, and its liver,

both in its structure and functions, is very different from ours. Its kidneys are situated in its head, and its heart in the middle of its back. In order to grow it has to retire from active life, for it first has to get rid of the skeleton that cramps it in, and then grow a new and larger one. Certain of the arthropods, such as the insects, breathe in a manner quite different from that of the vertebrates. A net-work of air-tubes permeates the body and opens on to the exterior at a number of places in the body-wall. The animal pumps air in and out of these tubes by rhythmical movements of its whole body.

Enough has been said to show that there is a fundamental difference between vertebrates and arthropods. Each of these phyla contains an immense variety of creatures. The insects alone, for instance, one division of the arthropods, contain more species than all the other animals put together. But Nature has by no means exhausted her diversity by creating these creatures. The molluscs, for instance, are an example of another phylum constructed on a radically different plan. It comprises a large variety of creatures, such as oysters, snails, octopuses, and cuttlefish. These creatures have no skeleton at all, but most of them have shells, double as with the oyster, or single as with the snail. The largest invertebrates known belong to this phylum, for cuttlefish have been found over fifty feet in length.

Another radically different plan runs through the Echinoderms, comprising star-fishes, sea-urchins, and so on. And still other plans of organization are found in the different sorts of worms, various sea creatures such as jelly-fish, corals, etc., and the sponges.

The fact that each of the great phyla is built on a fundamental plan leads us to suspect that all the variety of creatures that constitute a phylum are descended from a common ancestor. We can imagine that successive variations on the common plan would, in time, give rise to the present great diversity of creatures. But this remains, of course, merely a surmise until we have evidence that such variations have actually occurred. The structural resemblances however, do help us to suppose that all the vertebrates, for instance, have come from one common source. We may say as much of each of the other phyla, so that we could suppose that the whole animal creation comes from about a dozen primitive forms. The next step would be to see whether we could not whittle down this number by tracing resemblances between the great phyla, showing how they might all have branched off from some primitive form. Biologists have looked for connecting links between the great phyla, not altogether unsuccessfully. But the evidence is altogether insufficient at present to enable us to link together all the different

phyla. No convincing transition between, for instance, the vertebrate and the invertebrate has yet been put forward.

In any case, the whole of this speculation supposes that living creatures can, by successive modifications in succeeding generations, be turned into quite different creatures. There is very good evidence for this supposition, and it comes from various sources. Let us consider, first, the evidence from the existence of vestiges. The existence of useless vestigial organs is to be found in many animals and plants, and seems to be quite inexplicable except on the theory of evolution. The whale, for instance, is a mammal, a warm-blooded creature breathing air, and seems to be descended from some four-legged creature that took to the sea. The fore-limbs have turned into flippers. Indeed, a whale's flipper contains the skeleton of a well-developed fore-limb. But the whale presents nothing externally that corresponds to hind-limbs. Dissection, however, shows a small isolated group of bones which corresponds to a rudimentary pelvis and hind-legs. We cannot but suppose that these are the useless vestiges of organs that were once useful. Rudimentary hind-limbs are also to be found in some snakes, and this, in conjunction with their other anatomical characteristics, suggest that they are descended from some lizard-like creature. There is good evidence, as we

shall see later, that the horse is descended from a three-toed animal, and in the present horse, on either side of the toe that has become his hoof, may be found the vestiges of the other two toes. Man himself possesses numerous vestigial structures—according to some authorities, well over one hundred. We have, for example, a set of muscles to move our ears, but except with a few individuals here and there, the power of using them has been lost. At the lower end of the vertebral column we have the rudiments of a tail. In some animals the appendix is a well-developed and useful organ. In man it has become small and useless. These examples could be multiplied, and instances given, not only from animals, but also from plants.

These facts certainly lead us to suppose that, in the course of time, very great changes in organisms have taken place. More evidence for this idea is provided by the study of embryology. Most living creatures originate, we have seen, from the union of two cells, an ovum and a spermatozoon. The subsequent development of the creature, from inception till birth, is the subject of embryology. This study forms a powerful support of the theory of evolution. For, in the course of its development, the embryo of a higher animal passes through stages characteristic of lower forms of life. The embryo of a cat, for instance, or of a snake, hen, or even a man,

starts off as if it were going to become a fish. The structure of its heart, main arteries, and neck system are all like those of a fish. The embryos of all air-breathing vertebrates pass through these stages. It is difficult to imagine why this should be, unless these vertebrates have descended from a fish-like ancestor. The changes can be pursued into more detail, and some authorities have gone so far as to say that the development of the embryo gives a sort of summary or recapitulation of the actual course of evolution that has given rise to that particular creature. This statement is not now regarded as precisely true, since certain stages of evolution may be greatly abbreviated in the development of the embryo, or even omitted altogether. Also, stages in the development of the embryo sometimes refer back, not directly to an adult ancestor, but to the embryo of an ancestor. Nevertheless, the general course of evolution seems to be strikingly revealed by the development of the embryo, and this development seems to be quite inexplicable unless we suppose that evolution has occurred.

We have seen that the examination of living creatures, existing now, makes us strongly suspect that a process of evolution has occurred. The fact that all the varieties of animals and plants seem to be built up on a few fundamental plans of structure, the fact that so many creatures have useless vestigial

(*Photo, Will F. Taylor.*)

Stratified rocks.

organs, and, perhaps most striking of all, the amazing process of embryonic development, all lead us to suppose that many of our modern species must have been evolved from earlier, and, in many cases, more rudimentary forms. If we could journey backwards in time, then, if the theory of evolution be true, we ought to find the world of living things constantly changing. Certain highly organized types would disappear completely. Others would be replaced by fewer and simpler forms. If we went sufficiently far back we should, if we are to take the facts of embryology as indicative, find that all air-breathing vertebrates had vanished, and that the highest developed vertebrates were fishes. Farther back still even the fishes would disappear, and the world would be populated only with various forms of invertebrate life. And so we would continue until we finally arrived at the most primitive form of life, whatever that may have been.

We cannot make this journey in time; we cannot watch the evolutionary process. But it so happens that the history of a large part of this process has been preserved for us in the earth's crust. With this evidence, as we shall see, the process of evolution is removed from the region of plausible surmise; it must be accepted as a fact.

§ 2. The History of Life

We know the constitution of the earth's crust to a considerable depth below the surface. Vertical sections of considerable extent often occur naturally; others are brought about artificially, as by railway cuttings, mines, etc. An examination of these sections shows us that the part of the earth's crust accessible to us is composed of layers of different materials. We have layers of chalk, sandstone, clay, granite, etc. By patient comparisons made in all parts of the world, geologists have worked out the correct order of these layers, that is to say, they know *the order in time in which* these various layers were deposited.

From the time that the earth solidified there have been constant alterations in the areas occupied by the sea and by the land, and also in the heights of the land above sea-level. The formation of great mountain ranges has been followed by their demolition, over the vast periods of geologic time, by the agency of rains and winds. The transference of this high land into the water areas has caused the latter to overflow and periodically to flood more or

less of the land areas. By successive depositions the various geologic layers have been formed, and subsequently, through upheavals consequent on the shrinkage of the earth's crust, or, in some cases, of volcanic action, raised above the surface of the water. These alternations were accompanied, as geologic observation shows, by great variations of climate.

These processes, it must be understood, are still going on. In 1912 the United States Geological Survey stated that the surface of the United States is being denuded at the rate of one inch in 760 years. This means that the streams of that country are delivering into the seas and oceans 783 million tons of matter every year.

Together with this sweeping away of the soil, we see that any animal and plant remains that happen to be present in it will also be swept away. When, after a long period of such deposition, these great sedimentary layers again rise to the surface, we shall find these remains buried in them. We are therefore able to say, from the inspection of such layers as are accessible to us, what animals and plants inhabited the earth in those distant ages. The result is very interesting, and strongly confirmatory of the theory of evolution. For we find, as that theory requires, that the simpler organisms occur in the earlier layers, and the more advanced organisms in the later layers. Further, we can, in some cases,

find the connecting links between the earlier and later forms distributed through the intermediate layers. There is sufficient evidence of this kind, as we shall see, to establish definitely the fact that evolution has occurred.

The total thickness of the known geological layers, or *strata*, as they are called, would total about one hundred miles. Of course the whole of these strata are not encountered at any one place. The haphazard way in which they are formed, dependent on local conditions, would obviously prevent that. The various layers have reached their maximum thicknesses in various regions. But if the maximum thicknesses yet observed for all the geological strata were added together we should get *a total thickness* of something like one hundred miles.

For convenience of reference and description geologists have divided these strata into eras, just as a book is divided into chapters. The earliest era, the first strata to be laid down, forms the Archeozoic era. Then comes the Proterozoic, and after that the Paleozoic, in which vertebrate life first appears. There remain two more eras, the Mesozoic and the Cenozoic ; the last of which extends up to, and includes, modern times. As we have already seen, the total age of the earth may be estimated, in round figures, as about two thousand million years. The ages attributed by geologists to the

various eras fit in with this estimate. The age of the earliest Archeozoic era can be estimated only very vaguely, but it is estimated that about one thousand million years have elapsed since the beginning of the Proterozoic era, about five hundred million since the beginning of the Paleozoic, about one hundred and seventy-five million since the beginning of the Mesozoic, and about fifty million since the beginning of the Cenozoic, or modern, era.

For a description of the earliest forms of life that appeared on earth we have to depend on our imagination, guided, of course, by a sense of probability based on scientific knowledge. For the earliest forms of life have left no records of themselves in the rocks. We may readily imagine that they were too small and too soft to leave any such record. We may suppose that they were bacteria-like organisms, for we cannot imagine that anything so complicated as a cell emerged at one blow, as it were.

We have evidence that life had proceeded a long way in its development before it began to leave any record of itself on the rocks. The reason probably is that the early animals possessed no sufficiently hard parts. The hard parts of an animal are formed through the secretion of lime, and the lime-secreting habit did not arise until comparatively late. Throughout the Archeozoic rocks life has left

hardly any traces at all. There are indications that some primitive plant forms and worm-like creatures may have existed. Even such traces, we may remark, point to a very considerable development of life, for we must suppose that the numerous forms of life between these two extremes also existed. And these forms are a long way removed from the single-celled organisms that must have preceded them. As we know from observation of present forms of life, there are numerous steps intermediate between a single-celled organism and such a creature as a worm. If worms actually existed in the Archeozoic that fact points to the existence of a great diversity of other living forms. The records of life in the Proterozoic era are also scanty, but we have definite evidence that, by the close of that era, most, if not all, of the invertebrate phyla had been developed.

By the time we come to the next era, the Paleozoic, the lime-secreting habit is well under way, and we find abundant records of various forms of animal life. *During this great era an immense variety of* creatures came into existence, some to develop into modern forms, some to become extinct, and some to persist practically unchanged up till our own day. So far as the evolution of the invertebrates is concerned, we may consider their development throughout the Paleozoic era to be essentially one of detail. But a crisis of the first order, perhaps the greatest

crisis in the whole history of evolution, occurred during this era. That was the rise of the vertebrates.

The disadvantage of the invertebrate principle of construction is that it is difficult for it to find room for the two important factors of strength and agility. It is at its best when conditions are such that but little effort is required to maintain life. A sponge, for instance, is entirely sedentary. Jelly-fish float at the mercy of tides and currents, worms and molluscs move feebly, if they move at all. Generally speaking, invertebrate forms of life are, at best, sluggish creatures. This is true, in particular, of marine invertebrates. Of those invertebrate forms that have adapted themselves to life on dry land we have, in the arthropods, many creatures of great agility. They do not, however, develop great size and strength. The most successful of the invertebrates, from the point of view of its incorporation of these two factors, is the cephalopod. Some of these creatures reach a length of fifty feet. Also they can, when pressed, move with considerable speed. They do this by sending out violent jets of water through a tube placed under their mouths. The back pressure of these jets enables them to achieve a jerky backward motion, a method which consumes a great deal of effort in proportion to the effect it produces. As a method of propulsion it is nothing like so efficient as the method developed by the fish.

The fish is a vertebrate, and the earliest vertebrates of which we have any record were fish-like forms. These early vertebrates were not sea creatures. They are found in fresh water deposits, and it seems likely that they have developed in response to the greater demands made by flowing waters, such as rivers, compared with static waters. The increased power of controlled propulsion, it is thought, led to the development of the vertebrate system of construction, which has great advantages for this purpose. This increased power was necessitated, it is probable, by the great land upheavals which occurred at the close of the Proterozoic era. The static terrestrial waters were thus converted, by the slope of the land, into moving waters, so that only those creatures capable of resisting movement could remain in their environment.

The next great crisis in evolutionary history, as the fossils show, was the emergence of vertebrates on dry land. To achieve this the fish had to develop two new attributes. It had to develop a lung-breathing mechanism, and it had to develop some method of moving on dry land. There are still in existence fishes which are double-breathing creatures. Besides their gills they have developed lungs, and in times of drought, when the water in which they live is becoming dried up and muddy, they rise to the surface and gulp air into their lungs.

Three or four sorts of these fishes are living now, and it is generally accepted that land vertebrates have descended from a common ancestor of these. Fishes that developed lungs in this way did not all go on to the conquest of the dry land. In the case of those fishes who did not go on, the new lung mechanism developed into the swimming bladder, and thus became a device which improved the creatures adaptability to its water habitat.

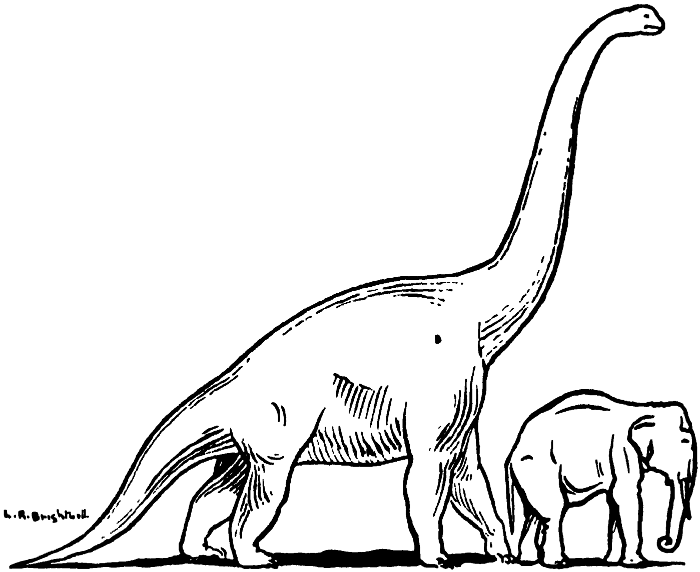
The origin of the second accomplishment, that of progressing on dry land, is still a matter of conjecture. There are some modern fish, however, which are able to move on dry land by the aid of their fins, so that, although we have not yet any direct evidence as to how the early fish accomplished this, the fact that they did so does not present any insuperable difficulty.

But even when these two difficulties had been overcome, the fishes that took to dry land had to face yet another difficulty. All the early fish were carnivores, and although the land, at the period of their emergence, was well covered with plant life, there was but very little animal life that they could use as food. A few primitive scorpions and insects would be all they could devour. For the most part, therefore, these early amphibians went on living and eating in the water. Even now, there are very few amphibians which have entirely freed themselves

from a water existence. Nearly all of them have to pass their youth in the water. Nevertheless, there were some of these early creatures which did successfully adapt themselves to the new life, and from them are descended *all the land vertebrates of the* present day.

The first of the vertebrates to achieve the complete conquest of the dry land was the reptile. The true reptile, developed from the amphibian, was fully developed by the end of the Paleozoic era. This development was probably connected with the increasing aridity that set in at that time, leading to the drying up of shallow waters, and thus making the old amphibian style of life more and more difficult. But the great period of reptilian evolution occurs during the next era, the Mesozoic era. For a period of one hundred million years the reptiles were the dominant form of life. They invaded all three of the great regions—water, land, and air—and amongst them were both herbivores and carnivores. Amongst the land reptiles were the biggest land animals that have ever lived. Many of them weighed more than thirty tons, and some more than forty. They were the most dominant group of animals that had yet appeared, and, as we have said, their reign was a very long one, namely, one hundred million years. And then they suddenly disappeared, nobody knows why. It is thought that the change

of climate at the end of the Mesozoic era, the increased cold and aridity, may have had something to do with it. Also, it has been noticed, although not fully understood, that animals which go on



The largest known dinosaur from British East Africa compared with an Indian elephant.
Brachiosaurus—from remains in Field Museum, Chicago, and Natural History Museum, Berlin.

specializing in size and strength sooner or later reach a "dead end." And it may be that the disproportionately small brain of the reptiles had something to do with their fate. A man weighing twelve stones has a brain weighing 3.3 pounds. This is

in the proportion of half a hundredweight to a ton. The brontosaurus, one of the great Mesozoic reptiles, weighed thirty-seven tons, and had a brain weighing 2 pounds. This is less than one ounce per ton, compared with the man's half-hundredweight to the ton.

We have said that the reptiles, besides adapting themselves to life in the sea and life on land, also invaded the air. They never became true fliers, however; they never developed wings. Their flight was merely a sort of prolonged leap, a parachuting glide through the air. The mechanism for this was a ridge of skin along the sides of the trunk and limbs. In some cases this ridge became a wide membrane uniting limbs to neck and tail. With this spread membrane the creature would launch itself into the air, steering by its tail. True birds, warm-blooded and feathered, appeared during the Mesozoic era, and there can be no doubt that they descended from a reptilian stock. The earliest known bird, *Archeopteryx*, a fossil belonging to the Mesozoic era, has many reptilian characteristics in the skull, jaw, forelimbs, and so on. Later specimens from the Mesozoic have become much more bird-like.

During the rich Mesozoic era another of the great advances in the history of life occurred. Mammals were developed. Mammals being, like birds, warm-blooded creatures, have a greater capacity

of adaptation to various climates, and can keep up a more constant activity than any other animals. But during the Mesozoic era the dominance of the reptiles was supreme, and the only mammalian remains belonging to that time are those of small and imperfectly developed creatures. It was not until the next era, the Cenozoic era, when the great reptiles had perished, that the mammals went on to their full development. Mammals may be arranged in three grades of development—monotremes, marsupials, and placental mammals. The monotremes lay eggs, as the reptiles do, although the young, when hatched, are suckled by the mother. The marsupials have advanced a stage beyond this. They bring forth their young alive, but very imperfectly developed, so that they have to carry their young in pouches, where they spend their infancy absorbing nutriment from the mother. The kangaroo is a specimen of this stage of development. The placental mammals, to which all the highest forms of life belong, bring forth their young in a highly developed state. The higher mammals also have better developed brains than the more primitive types. No placental mammals appear during the Mesozoic era. The fossils that have been found all belong to marsupials, or monotremes. Also, judging from their remains, they were small in size and insignificant in numbers.

It was during the next era, the Cenozoic era, that mammalian evolution was in full swing. All the main types of mammals—the horse, tiger, cattle, sheep, elephant, whale, etc.—were developed during this era. Also, various types were developed which, for one reason or another, were not destined to survive. We may instance the baluchitherium, a gigantic creature weighing about twenty tons, and able to browse on leaves more than twenty-five feet from the ground.

The next great stage in the history of life is the emergence of man. Man's nearest relatives are the so-called anthropoid apes—the orang, chimpanzee, gorilla, and gibbon, and it is supposed that these, together with man, are descended from a common stock. The history of this descent is not yet known. It is thought probable that man descended from a lemur-like creature, the ancestor of the monkeys and of the apes. But the intermediate links have not been found. Remains of primitive men have been found, however, men much more ape-like than ourselves, and the earliest of these remains go back for approximately half a million years.

The remains of primitive man that have been discovered do not form a connected series leading us from some ape-like ancestor on to modern man. Several lines of development seem to have been struck out from the primitive creature that began it

all. Some of these lines diverged into the various species of monkeys and apes. Others diverged into various species of men. Our own species is the culmination of one of these lines of development. Other species of men that were evolved have perished and left no descendants. From the human remains that have been found it is impossible to reconstruct the history of the development of our own species. It may be that none of them are directly related to us at all. Or it may be that present man is descended from a blend, as it were, of two or more of these primitive types. There are various and conflicting opinions on this point.

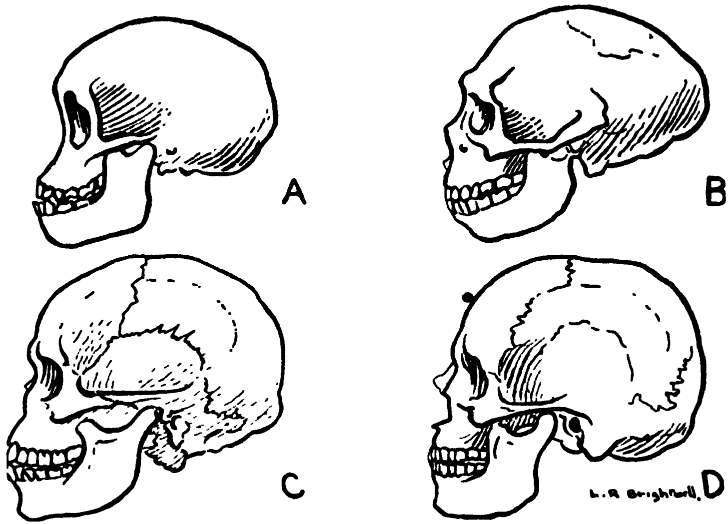
What are possibly the earliest of human remains were discovered by a Dutch military doctor named Dubois in the neighbourhood of the village of Trinil, in Java, in the year 1891. These remains consisted of the roof of a skull and a single molar tooth. Later a thigh-bone and a second molar tooth were discovered. These finds were immediately made the subject of sharp controversy. Some said that they were nothing but the remains of a large gibbon. Others objected that there was no reason to suppose that the remains all formed part of the same animal. But since then similar remains have been found in the neighbourhood of Pekin, and it is now generally accepted that the Javanese remains are those of a primitive kind of man. From small fragments

anatomists are able to deduce a great deal. They have deduced that *Pithecanthropus*, as the Javanese man is called, had a brain of considerably less than modern human capacity. In his posture, however, he was not at all ape-like. It is probable that he carried himself nearly as erect as we do ourselves. Judging from the characteristics of the strata in which the remains were found, it is thought that Pithecanthropus must have existed 400,000 to 500,000 years ago.

Another relic, also very ancient, is a lower jaw found at Mauer in southern Germany in 1907. This jaw is very primitive, heavy, and massive, and in these respects might very well be the jaw of an ape. The teeth, however, both in themselves and in the way they are set in the jaw, are completely human. In other respects, also, the fragment is human. The creature to whom this jaw belonged was called by its discoverer *Homo Heidelbergensis*, to indicate that it is a species of man. Unfortunately it is unique. This is the sole relic of this particular species of man that has been found. Its age is probably about 400,000 years.

A find in some ways even more singular is that of the remains of Piltdown man, *Eoanthropus*, found at Piltdown, on the Ouse, Sussex, by Mr. Charles Dawson, a local lawyer and antiquarian, in 1913. These remains consist of an incomplete skull and a

lower jaw. Here again, many authorities thought at first that these two things did not belong together. They thought that while the skull might be that of a primitive human being, the jaw belonged to a chimpanzee. A few years later, however, a second



Human types.
A. Java Ape Man. B. Neanderthal.
C. Tasmanian. D. European.

specimen was found some two miles distant, and thus made it quite clear that skull and jaw really do belong together. It is now agreed, therefore, that Eoanthropus was a creature combining the characteristics both of man and chimpanzee. These remains are certainly very old, and it may be that

they are the oldest human remains that have yet been discovered.

Fragments of yet other species of primitive man have been found in various parts of the world, but the dating of these fragments is, for the most part, very uncertain. We are on much more solid ground when we come to consider the remains of Neanderthal man. Numerous specimens of this race have been found in different European countries and in Palestine. Neanderthal man was a short, clumsy, powerful creature, unable to walk fully erect. His brain was even larger than that of modern man, but its higher centres were not so well developed. He buried his dead ceremonially, understood the use of fire, and was a skilled worker in flints. He was a contemporary with the reindeer, rhinoceros, mammoth, and so on, animals that lived in Europe during the last Ice Age. It is probable that the whole race died out about 20,000 years ago, although some authorities think that certain modern peoples are in part descended from a Neanderthal stock.

Later remains than those of Neanderthal man may, with justice, be described as those of modern man. *The most celebrated of these pre-historic,* but modern, species of man is the *Cro-Magnon* man, so called from the place where his remains were found. This race has been described as " in

almost all respects the most perfect man physically that has come within our knowledge." Many skeletons of this race have been found. The average height of the males was well over six feet; the women, however, were little taller than those of the present day. Their skulls are entirely modern. These men, besides being skilled workers in flints, were artists of considerable accomplishment and power, as we see from the sculpture, engraving, and painting that has been found in great abundance in and upon the walls of their caverns. This race has now ceased to exist. North and south of the Himalayas there are peoples with very much the same facial characteristics as the Crô-Magnon, and the Sikhs resemble them in stature and bodily build. Still other remains of modern man have been found, but their antiquity is a matter of dispute.

§ 3. The Process of Change

We have given a sketch—a very brief sketch—of the history of life on this planet. We see that the *time order in which* the various animals arose makes it practically impossible to avoid the conclusion that a process of evolution has occurred. The question now arises, how did this process of evolution come about? What caused it?

We have seen that genes are the factors of heredity, and that genes can undergo mutations. The characteristics of an animal are determined by the particular genes that its cells happen to contain. If the genes are changed, the characteristics of the animal are changed. Such changes, as we have said, are constantly occurring in nature. In the vast majority of cases such changes lead only to minute variations in the organism—variations so slight as to escape detection. In other cases the changes may be conspicuous enough to be noticed by a trained observer. And in some cases, it has been found, a single mutation, a change in one gene, may be sufficient to produce striking results. Thus the colour of an animal's hair may be changed from

black to brown, or from black to yellow, by a single mutation. Another single mutation can change the colour of the eyes. The loss of horns in cattle, and the loss of the tail in cats, can also be traced to a single genetic change.

Since mutations are constantly taking place it follows that, sooner or later, descendants will arise which differ in some respect from their ancestors. Some of these differences may be of a kind which do not influence the creature's life in any way, but some of them may be of a kind which has a direct bearing upon his chances of survival. They may be advantageous, or they may be disadvantageous. For the environment is continually pressing upon the creature, putting a premium upon some characteristics, and penalizing others. Those creatures whose variations from the normal form fit them more perfectly to their environment will obviously have a greater chance of surviving and reproducing their kind. They hand on the change that has occurred in them to their descendants. These descendants will, in due time, suffer further changes, which may, in their turn, be either hindrances or helps.

We see that two factors are involved. There are the random variations in the organism, and there is the selective action of the environment on these changes. This selective action, we must remember, is not always in the same direction. For instance,

an animal which can live within a certain range of temperature may undergo a mutation which fits him for a different range of temperature. If, now, the climate happens to change in a corresponding manner, the mutation is obviously an advantage to him. But if the climate should change in the reverse direction, or remain as before, then he is obviously at a disadvantage. Similarly, a great armour-plated reptile doubtless found his armour an advantage as long as he lived in marshes, for the water took off much of his weight. But when the marshes dried up he must have found that he could hardly crawl about. For millions of years mutations in the direction of more and more armour had proved advantageous. There came a change in the environment, and the advantage became a disadvantage.

Can the whole history of life on this planet be explained as due to chance mutations and the reaction of the environment on them? Perhaps the majority of biologists find this explanation satisfactory, although there are a number of dissentients. In favour of the theory we must emphasize the enormous length of time during which the process has been going on. We are dealing, it must be remembered, with many hundreds of millions of years. It is not unreasonable to suppose that the accumulation of chance variations over so great a period of time might be sufficient to explain the

diversity of living things. Further, we must remember that the changes are not always small. And we do not know at what rate mutations took place in the past.

There are some biologists, however, who think that there is evidence, in some cases, that mutations did not take place entirely at random. In these cases the succession of mutations, they assert, was continually in the same direction. These mutations take place in accordance with some sort of inner drive, and they continue even when they are no longer of advantage to the animal. Indeed, the variation may be in a direction which is of positive disadvantage to the animal. This theory, the theory of Orthogenesis, has secured a good deal of attention from biologists, but it is by no means generally accepted.

We have already discussed the pre-Darwinian theory of evolution, Lamarkism, which attributed variations to personal strivings of the animals concerned, and we have already said that this doctrine is pretty generally rejected. It is indisputable, of course, that changes in the organism can be produced in this way, but the evidence goes to show that such changes are not inheritable. They do not effect the genes carried by the individual, and therefore they cannot be transmitted.

There are three types of variations, which may

be classified as fluctuations, Mendelian combinations, and mutations. Fluctuations are those changes in the developed organism which come about through the use or disuse of various parts, or through changes in food, climate, etc. Such changes do not affect the germ plasm, and are not inheritable. Mendelian combinations occur simply because, as we have seen, the offspring selects half its chromosome outfit from its male parent and half from its female parent. There are usually numerous ways in which this combination can be effected, and each new combination determines, of course, a new set of characteristics of the offspring. Thus variations can be produced without altering the constitution of any of the genes, but merely by reshuffling them. Such variations are, of course, inheritable, and they have played a certain part in providing the materials for evolution. But the really fundamental steps in evolution come about through mutations. The causes of the mutations that occur in nature are not known. It seems that these causes must spring partly from the structure of the germ plasm itself and partly from the outer environment. Although mutations seem to occur at random, it is not true that every conceivable mutation occurs. As T. H. Huxley said, "Whales never produce feathers, nor birds whalebone." But neither the mutations, nor the limitations on the mutations, can at present be explained.

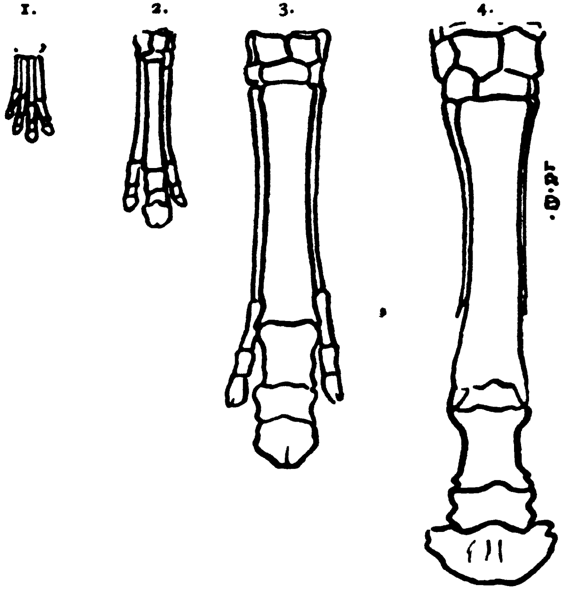
The geological record makes it clear that higher forms of life appeared later than the lower forms. But it would obviously be incorrect to represent the process of evolution as consisting in the supersession of lower forms of life by higher forms. Creatures at all stages of development continue to exist side by side at the present day. The earth still supports and nourishes amœba as well as men. The common lamp-shell, lingula, has persisted unchanged since the beginning of the Paleozoic era, a period of five hundred million years. In such cases it seems that the creature has developed to a point where it is so perfectly adapted to its environment that there is no profit in further change. As long as the environment does not vary in any essential respect, the creature persists unchanged. There are cases, also, where an actual retrogression, a degradation from higher to lower, has been found an advantage. Consider, for example, sacculina, a creature which is parasitic on various sorts of crabs. It is without sense-organs, limbs, or digestive system. It is little more than a bag of reproductive cells. It affixes itself to the crab, sends out branched roots in all directions into its body, and sucks nourishment out of it. Yet this creature was once a free-swimming crustacean with jointed limbs, external skeleton, and the rest of it, for that is the form in which it begins life, when newly hatched from the egg. It has

found an easier way of living, but only at the price of degenerating. Other instances of retrogression could be given. Successful adaptation does not always mean an advance in the evolutionary scale.

A very good instance of advancing evolution is given by the history of the horse. Primitive horses are found at the beginning of the Cenozoic era, and their subsequent development can be traced right up to modern times. The earliest horses that have been found are small creatures, about a foot high, and with four toes on the forefeet. As time goes on we find one of these toes developing, and the others shrinking. In the meantime the animal is growing larger, and its teeth are becoming more efficient. Presently the animal is a three-toed animal, the other toe having shrunk to a mere splint. The two outer toes of the three begin to shrink, so that the animal, although possessing three toes, only runs on one. The shrinkage of the two toes continues, little by little, until, in modern times, they become mere vestiges. Other developments have accompanied these, all tending towards greater strength, speed, and efficiency. The history of this development has been worked out from many tens of thousands of specimens that have been found. An almost equally detailed ancestry can be given for some other animals.

It is worth noticing that the evolution of the horse has been, strictly speaking, a progress in specializa-

tion. The horse has adapted himself more and more perfectly to one particular way of life—a herbivorous life on great smooth plains. Here his wonderfully



The evolution of the " horse's hand " or pre-foot.

1. Hyracotherium. (Eocene.) 2. Mesohippus. (Oligocene.) 3. Hipparion. (Pliocene.) 4. Modern Horse. (Recent.)

strong and efficient teeth and his great speed are advantages in procuring his food and avoiding his enemies. But the very perfection of his adaptation has ruled out all other possibilities for him. If his

present way of life were, for some reason, closed to him, he could not take to some other way of life. He could not become carnivorous, or learn to climb trees, or take to the water or the air. Compared with the early reptilian stock that did all these things we see that the horse has lost all plasticity. The large carnivores, the natural enemies of the horse, and developed at the same time, are similarly specialized.

In studying some particular line of evolution we often find that different specimens, corresponding to different periods of time, have been found in different parts of the world. In fact, the distribution of animals and plants, present and past, is often, at first sight, very puzzling. But the matter becomes clear when we take into account the great geographical changes which, as geology informs us, have taken place in the past. Land bridges once joined areas which are now separated by seas, and once impregnable barriers of water divided into sections what is now one connected stretch of land. Australia, for instance, was not always divided from the rest of the world. But the separation occurred before the development of true placental mammals. Hence only the earlier types, monotremes and marsupials, inhabited Australia. The continent of Africa was once divided by seas into two separate areas. And such alternations have often taken place

more than once in geologic time. The evolution of any particular type of animal depends very largely, of course, on local conditions. In the history of many creatures there have been bursts of evolution, as it were. These bursts originate in particular regions, and the new type of creature then spreads in the ordinary way. In the meantime it may be that certain districts which were invaded by the more primitive type have become cut off from the region of the new development, and that there is nothing in the circumstances of those districts to cause a similar outburst. Thus the marsupials which got to Australia were left marooned, and went on being marsupials for many millions of years.

§ 4. THE LIFE CYCLE

THE primary difference between plants and animals is to be found in their feeding. Plants are able to take their food direct from the inorganic nature that surrounds them. Animals cannot do this. All animals, in the last resort, get their food from plants. In many cases they do not do this directly, of course. There are ticks that live on plants, small birds that live on ticks, and bigger birds that live on small birds. But in the absence of plants all animal life would be impossible. The chemical substances taken in by plants, are, by them, *built up into more elaborate compounds*, and it is only in this more complicated form that they can be assimilated by animals. When the animals die and decay the complicated compounds are broken down and their elements are thus restored to the realm of inorganic nature. In this form they are again of use to plants, and so the whole cycle begins again. It is true that a cycle would exist even without animals. The decomposition of dead plants would bring the chemical substances they absorbed into circulation again. But the process would be

a slow one. The importation of animals into the cycle greatly quickens up the whole process. The animal-plant combination may thus be regarded as a sort of compound transformer of certain chemical elements.

The most outstanding of the chemical elements that takes part in this cycle is carbon. In the number, variety, and complexity of its compounds, carbon is unique. It is the organic substance *par excellence.* Other elements, such as oxygen, nitrogen, phosphorus, etc., play a very significant part in life processes, but carbon, more than any other element, seems to be truly indispensable. The carbon that life draws upon exists as a compound—carbon dioxide, whose formula is CO_2. There are about two and a half million million tons of this substance in the earth's atmosphere, and perhaps twenty to twenty-five times this amount in the oceans, lakes, and rivers of the world. It has been estimated that about one-thousandth part of this total takes part in the life cycle.

Green plants, under the influence of sunlight, take CO_2 direct from the air. They get rid of the oxygen, and build up a number of complex compounds with the carbon. Animals devour the plants, and the carbon they thus obtain goes, in combination with oxygen, to form carbon dioxide again, and is breathed out by the animal. Thus the cycle is

complete. This cycle, however, by no means accounts for the whole of the circulation of carbon dioxide that is going on in nature. Besides the breathing of animals, their decay also restores a certain amount of carbon dioxide to the atmosphere. The decay of plants does not lead to so rapid a restoration. Indeed, a considerable quantity of their carbon becomes locked up in the form of peat and coal, for these, as we know, are both formed by dead plants. During the course of geologic ages a great deal of carbon has been stored up in this way, carbon taken, in the first place, from the air. In our present epoch, man, by burning peat and coal, is busily restoring this carbon to the air at a great rate. If no compensating factors were at work, our coal fires and metallurgical furnaces would double the amount of carbon dioxide in the air in about five hundred years. Volcanoes and mineral springs also pour vast quantities of carbon dioxide into the air. Amongst the compensating agencies, those that withdraw carbon dioxide from the air, we must reckon, beside the formation of peat, the weathering of rocks. In the process of weathering, rocks absorb carbon dioxide. It is difficult to give a precise estimate of the amount used up in this way, but it is certainly very considerable. It is calculated that the amount contained in the geologic rocks is thirty thousand times the amount now present in the

atmosphere. But the great equalizing agency is the ocean. This contains about twenty times as much carbon dioxide as the atmosphere, and maintains an almost constant balance, absorbing excess, and replacing deficiency.

The oxygen cycle is, of course, related to that of the carbon cycle, since carbon dioxide is a compound of the two elements. The essential function of plants is to separate the carbon and oxygen in carbon dioxide, while the essential function of animals is to recombine them. Some authorities hold that all the oxygen of the air has been formed from carbon dioxide by the agency of plant life. The question is still, however, somewhat obscure.

Another of the substances indispensable to living organisms is nitrogen. The cycle of this element is far more complicated than that of carbon. Life needs this element, but the problem of getting an adequate supply of it is very complex. Yet the amount of nitrogen present in the atmosphere is out of all proportion greater than that of carbon. If we take a column of air resting on a square foot of the earth's surface, then this column contains over fifteen hundred pounds of nitrogen. It only contains a quarter of a pound of carbon. But the fact is that free nitrogen, as it exists in the air, is of no use to the living organism. It is only when it is combined in certain chemical compounds that it can be as-

similated as food, and these compounds are by no means plentiful. It has been calculated that the amount of nitrogen which occurs in this form and passes through the life cycle is only about two one-millionths of the total nitrogen in the atmosphere.

It is possible that a few plants are able to take nitrogen directly from the air, but this is not the usual method. The task of reducing the atmospheric nitrogen to the liquid or solid form in which it is available for consumption is accomplished by a restricted class of organisms. These are the nitrogen-fixing bacteria. These creatures live in the soil and convert the nitrogen of the air into compounds which can be assimilated by the roots of plants. Certain leguminous plants—peas, beans, clover, alfalfa, have nitrogen-fixing bacteria lodged in the tubercles upon their roots, and the two organisms, the plant and the bacteria, work together to transform atmospheric nitrogen into an assimilable form.

Most plants derive their nitrogen from the ammonium salts, nitrites, and nitrates, that are present in the soil. These compounds, also, are attacked by certain bacteria, with the result that a certain amount of free nitrogen leaks back into the air. Other sources of nitrogen leakage are forest fires and the burning of wood and coal. All these operations lead to the liberation of free nitrogen into the air. Nitrogen, in a compound form, is absorbed

from plants by animals that feed upon them. Part of this nitrogen passes away from the animal as manure. Also, part of it remains in the bodies of dead animals. In both these cases decomposition leads to the restoration of a certain amount of free nitrogen to the air. The refuse from slaughter-houses is responsible for a considerable leakage. Modern methods of sewage disposal in large cities also lead to a considerable loss.

It is obvious that these losses must be made good if the life cycle is to continue. How are they made good? We have already seen that certain plants can get their nitrogen directly from the air. Volcanoes provide another source of supply. Volcanoes belch certain nitrogen compounds into the air, and these compounds are washed down into the soil by rain. Lightning, also, precipitates certain nitrogen compounds on to the ground. It has been calculated that the gains from these sources rather more than compensate for the losses.

Apart from these natural agencies, we must also consider the effect on the nitrogen cycle of man's activities. Man seems to have understood the use of manure from very early times. A great step forward was taken when the Chilean nitre beds were opened up in 1831. Without this discovery modern intensive agriculture, and the increase in population made possible by it, could not have come about. It

is an interesting fact, nevertheless, that a comparatively small proportion of the nitrogen obtained from Chile is used in manufacturing fertilizer. A larger percentage, indeed, nearly half the total product, is used for manufacturing explosives. In exploiting the nitre beds, as in exploiting the coal beds, we are, of course, using up supplies that we cannot replace. It is possible that the nitre beds are the result of volcanic activity, although this question is not yet settled. But whatever their origin, it is certain that they took long ages to accumulate, and that they are not being replaced anything like as rapidly as they are being exhausted. Fortunately, this fact need not give rise to any misgivings, for man has now found a way of fixing nitrogen directly from the air. There are several ways of doing this, and the artificial formation of nitrogen compounds from atmospheric nitrogen now takes place on a great scale. The war, of course, led to a great development of this young industry, since nitrogen compounds are required in explosives. In 1909 only 1 per cent. of the world's needs were supplied in this way. By 1917 the output had reached 30 per cent., and by 1920 had reached 43 per cent.

The amount of combined nitrogen produced in this way is small compared with the quantity washed down by rain all over the world. But the nitrogen compounds washed down by rain are distributed

indiscriminately over the earth's surface, on barren soil and fertile soil alike. The great advantage of making nitrogen compounds artificially is that they are within man's control, and can be applied where he finds them most useful.

Carbon dioxide and nitrogen are, as constituents of the atmosphere, distributed uniformly all over the world. The next element on our list, phosphorus, which is also of great importance in the life cycle, is not distributed in this way. It is a typical example of what are called the *inherently immobile* elements necessary to the living organism.

In general the virgin soil contains a certain store of phosphates. But, in course of time, and under cultivation, this store steadily decreases. Part of this loss is probably caused by rain charged with carbonic acid which dissolves the phosphates in the soil and ultimately washes them out to sea. But another part of the loss occurs through the fact that the phosphorus taken up into plants and then into the bodies of animals and men is not properly returned to the soil. The custom of burying human bodies, for example, although it returns phosphorus to the soil, does not do so in the way best adapted for crop production. But a much larger source of waste is to be found in our modern methods of sewage disposal, whereby a large amount of phosphorus is run off annually into the sea. At present we com-

pensate for this loss by drawing upon age-old accumulations of phosphorus in the phosphate rocks, just as nitrogen compounds were obtained from the nitre beds of Chile. In the case of phosphorus, however, we have no reserve supply corresponding to the nitrogen of the atmosphere. Phosphorus is a comparatively rare element, constituting only about 0.14 of the earth's crust. The loss of phosphorus, an essential element of the life cycle, is therefore a really serious, even alarming, matter.

Not all the phosphorus washed into the sea is lost, and we have here a very interesting example of a natural life cycle. Phosphates washed into the sea serve as food for marine vegetation, which is devoured by various sea creatures. Part of the phosphorus so assimilated goes to form the bones and shells, the hard parts, of these creatures, and, at death, falls to the sea bottom. Upheavals, such as occur in geologic times, sometimes raise these deposits above sea-level, and so we get our phosphate rocks. Another cycle is brought into being by the birds that prey upon fish. These birds, which flock in great hordes, have their nesting-places on rocky islands and shores, and here, in course of time, accumulate immense masses of their waste products, or guano, which is, in some cases, restored to the soil by man. Unfortunately these sources do very little to replace the loss of phosphorus which is

continually going on. It is calculated, for instance, that the United States is losing twice as much phosphorus as it quarries from its phosphate rocks; that is to say, its net annual loss is, in terms of phosphate rocks, about three million tons. It is not surprising, therefore, that many authorities regard the land's steady loss of phosphorus, with its inevitable result upon the food supply, as alarming.

Of the other elements that take part in the life cycle we need refer only briefly to potassium, sulphur, and iron. Deposits of potassium salts occur in nature. These deposits were controlled by Germany, and, during the war, methods were developed for obtaining potash from the waste of cement works and other materials. But when the German sources again became available these methods were discontinued. Sulphur compounds occur in abundance in Nature. Plants assimilate them, and, in their turn, animals. Animals excrete them, and they thus return again to the soil. Iron occurs in very minute quantities in the living organism, but it plays a very important rôle. It is the presence of iron in the chlorophyll of plants which enables them to obtain their carbon dioxide from the air. Most of the iron in the human body is contained in the red blood corpuscles, and here it acts as a carrier of oxygen, enabling the oxygen from the air in the lungs to be transferred to the tissues of the body.

Besides the transport of materials in the life cycle there is, of course, a flow of energy. This energy comes from the sun. The total amount of energy from the sun that is intercepted by the earth is less than one two-thousand-millionth of the sun's total radiation. A minute fraction of the rest of the sun's energy falls on other planets, but the great bulk of it is simply radiated away into space. Of the amount of energy that reaches the earth, only 65 per cent. is absorbed. The other 35 per cent. is reflected back into space, chiefly from the clouds. The amount of heat that actually reaches the earth from the sun would suffice to melt a layer of ice 424 feet thick every year. Of this amount of energy only 0.12 per cent. is absorbed by green vegetation, and this, therefore, is the amount of energy on which the life cycle depends. Expressed as a percentage this amount of energy sounds very small, yet it is, in quantity, equal to twenty-two times the energy afforded by the world's annual coal production. The greater part of this energy, 67 per cent., is taken by forests. The plants cultivated for human needs take 24 per cent.

We see that the total energy used by the life cycle is a very small fraction of the energy that the earth receives. A much greater fraction, about two hundred and fifty times as much, is used in the production of winds. Ocean currents also require a great deal

of energy. But the most important user-up of energy is the circulation of water by evaporation, condensation, and river flow back to the ocean. It has been calculated, for instance, that the expenditure of energy that occurs during the evaporation from one square kilometre of tropical ocean is over one million horse-power.

§ 5. THE EQUILIBRIUM OF NATURE

WE have seen that the elements which take part in the life cycle proceed through plants to animals and back to plants again, bacteria playing an essential part both in the building-up and the breaking-down processes. Animals could not live without green plants, and green plants could not live, in their present abundance, without animals. In any living community, the interdependence of the various organisms is very complicated. " The starting-point of a food-chain is normally among green plants, but from one and the same starting-point many food-chains may radiate out in different directions. In an English wood, for instance, plant-lice suck the juices of the twigs ; these, either before or after having fallen a prey to spiders, are eaten by small birds like tits and warblers, and these in their turn by hawks. The same trees may contribute to the hawk's upkeep in another way. They drop their leaves upon the ground, the leaves are eaten by earthworms, the earthworms by blackbirds scratching among the under-brush, and the blackbirds by hawks. A different line is started through the seeds of the

trees. Acorns and beech-nuts are nibbled by mice, and the mice are the chief support of tawny owls; and there are other chains running through woody branches or stem, to wood-boring insects and woodpeckers, through seeds and squirrels, through leaves and caterpillars or gall-insects, and so forth." * The food-chain of sea-creatures is similarly complex.

An astonishing thing about the constitution of any particular life community is its very great stability. The region inhabited by any such community, provided it has not been disturbed by man, has been inhabited by that community for ages. It is exceedingly difficult for any foreign organism to find entry in such a region. An instance is provided by Mount Ritigala, a solitary precipitous peak of less than 3,000 feet in the north of Ceylon. The island has a damp, tropical climate as a whole, but in the northern part, where Ritigala is situated, the climate is dry and arid. Nevertheless, the peak of Ritigala, which is cloud-capped, is decidedly moist. In spite of this the flora of the peak is practically identical with that of the dry region. Only comparatively few of the species characteristic of the moist part of the island have succeeded in effecting a lodgment on the peak in spite of the climatic resemblance. The community already established there is so stable that interlopers, al-

* *The Science of Life*, by Wells, Huxley and Wells.

though favoured by the climate, can only make good their footing with extreme slowness.

When the ground is clear, however, when no community is already in possession, life spreads itself with amazing rapidity. A celebrated example of this was provided by the immense volcanic eruption, in 1883, on the island of Krakatoa, between Sumatra and Java. This eruption was so intense that half the island was blown to pieces. Every vestige of life on it, as also on two neighbouring islands, was destroyed. Even islands fifteen miles away were three-parts devastated by the explosion. Ten miles farther away lay the islands of Java and Sumatra. If life was again to appear on the island, therefore, it would have to be from seeds borne a considerable distance on winds or ocean currents. Yet within three years some seventeen species of flowering plants had re-established themselves on the island, as well as a number of mosses and various kinds of fern. Ten years later there were no less than fifty species of flowering plants, tall grasses, shrubs, and a few trees. In 1906, twenty-three years after the eruption, there was a rich vegetation, including figs and coconuts. And there were mosquitoes, ants, wasps, birds, and lizards. Thus many more immigrant forms of life had established themselves in twenty-three years on the lifeless soil of Krakatoa than had suc-

ceeded, in geologic ages, in invading the occupied territory of Ritigala.

The forms of life that flourish in any region depend on such factors as the light, moisture, temperature, etc., of that region. If left to itself the region becomes populated, to the fullest possible extent, with the kinds of life best adapted to it. The life-community is then said to have reached its "climax," and, as we have seen, it is remarkably stable. As we proceed from the Equator to the poles we find that nature reaches various kinds of climax, depending on the climatic conditions. At the Equator the normal climax is the rain-forest, green all the year round, and with an immense abundance of great trees. As we go north and south from the Equator the amount of moisture becomes insufficient to support trees so closely ranked, and they become more spread out. In desert lands the trees, owing to lack of moisture, are smaller and sparser, and even the small plants can no longer cover the soil, but exist in broken and disconnected patches. As we pass into higher latitudes we come to wetter regions, and here we come to the great grass plains, the prairies and the pampas. In regions of high latitude, where conditions are severe, we find the lower forms of plant life—mosses and lichens—relatively abundant, until, as we approach the great ice-fields, we find only a few poor plants here and there.

Variations of altitude give us very much the same succession as variations of latitude. "We can start at the Equator, in the Congo rain-forest, and, by the vertical ascent of less than three miles to the peak of Ruwenzon, reach the same lifeless cap of snow and ice that we should have had to travel more than 5,000 horizontal miles northward to find in the mountains of Spitzbergen. And in our ascent we should have passed through belts of vegetation almost as diverse as in that long, horizontal poleward stretch. Above the tropical forest, park-like savanna forest, with richer, greener vegetation in the stream-gorges; and here and there bare and grassy stretches treeless. Then, as the cool and the mountain rains begin, a green forest of tree-heathers, all festooned with hanging moss. Above that, again, a still queerer forest of groundsels and lobelias grown to the estate of trees, looking not like any familiar terrestrial trees, but trees produced by some other planet. This gives place to mountain meadow, and this gradually to a true alpine flora, nestling in isolated tufts among the rocks. And, above this, rocks and ice and snow untouched by life." *

Marked gradations of life may also often be encountered in very small regions, as, for example, in and around a pond. From the centre to the edges we have zones, as it were, populated by different

* *The Science of Life*, by Wells, Huxley and Wells.

kinds of organism according to the different degrees of moisture, light, and so on, that they require. The natural tendency of all animals and plants is to multiply without limit, but actual conditions of temperature, etc., restrict each species to certain regions. Besides these checks on unlimited proliferation there are, of course, the checks imposed by competition. A few prickly pears were introduced into eastern Australia as a botanical curiosity. In a few years they had spread so as to cover thousands of square miles. At one time they were extending at the rate of an acre per minute. It looked as if the whole of eastern Australia would be covered by prickly pears. In the year 1907 there was a huge increase in mice in the State of Nevada. Birds and mammals were eating them at the rate of a million a month, but they continued to increase. Such outbreaks are usually brought to an end by disease. Terrific epidemics carry off the vast majority of the animals, and leave them much below their usual numbers. In any case, shortage of food would, of course, put a stop to the indefinite multiplication of any animal. It often happens, however, that when the food begins to run short, the animals migrate. The great locust swarms of history are an instance of this. An almost equally famous instance is provided by the migration of the lemmings, little rat-like creatures from Scandinavia. At certain periods

enormous hordes of them leave their breeding-grounds, and, overcoming every sort of obstacle —climbing walls and swimming rivers, make for the sea. This, also, they attempt to cross, with the result that every one of them is drowned. It is reported that a ship has steamed for a quarter of an hour through a mass of these swimming lemmings.

These periods of abundance occur very regularly. Nearly all species go through periods of increase and decrease. Their numbers rise to a maximum, sink to a minimum, and rise to a maximum again. And for any particular species the maxima succeed one another at equal intervals. The snow-shoe rabbit, for instance, has maximum periods occurring every eleven years. We find the same eleven-year period with the lynx and the red fox. In the case of the arctic fox the maxima succeed one another every three years. The great migrations of the lemmings also occur about once in three years. The cause of these cycles is not yet known.

We see that, in regions which have not been interfered with by man, a very delicate state of equilibrium exists. We have disturbing forces, such as those that lead to the over-production of some species, but, after a certain point, a correcting influence comes into play and the original state of balance is re-established. As we have seen, in every undisputed region of the world nature works towards the

climax appropriate to that region, and this state of climax is remarkably stable.

The great disturber of this state of equilibrium is man. We have already referred to the introduction of the prickly pear into Australia. Many similar instances could be given. Man's cultivation of plants and animals is not always an unmixed blessing. It often introduces a whole crop of new problems. The devastating march of the prickly pear in Australia, for instance, has been checked only after careful research. A deliberate hunt for enemies of the prickly pear was made in various countries, and, finally, four kinds of insects that feed on prickly pear, and on prickly pear alone, were discovered. These insects were imported to Australia, where they have now multiplied sufficiently to hold the prickly pear in check. This instance is typical. A recognized way of dealing with pests is to look for their natural enemies, and a great deal of successful research has been undertaken on these lines. The delicacy and complication of the balance of nature has only recently been recognized. Almost everything that man does destroys this balance, often in quite unthought-of ways. It was discovered, for instance, that over large regions cattle, pigs, sheep, and horses were being affected by mysterious diseases which had harmful effects on their growth, their fertility, and their yield of meat, milk, wool, and skin. Ulti-

mately it was found that these diseases arose from a deficiency of mineral salts in the animals' food—such mineral salts as those of iron, calcium, phosphorus, etc. Man was rearing more creatures in these regions than the ground could naturally support. Moreover, by shipping off the carcasses and skins of the animals he prevents the absorbed minerals from returning to the soil. In a state of nature an animal dies in the place where it feeds, and its products have a chance of returning to the soil of that region. Man interrupts this cycle. The investigation of this problem has, amongst other things, led to the breeding of new and more efficient kinds of grass. In the breeding of these grasses, as in the breeding of more efficient kinds of wheat, we have a promise of the control that more complete biological knowledge will enable man to achieve. The cattle, pigs, etc., that man breeds for his own use are, of course, another illustration of the way in which the application of biological principles enables man to improve upon wild nature.

Other illustrations of the interconnection of nature, unpleasant, but of the greatest importance to man, is given by the natural history of many diseases. Malaria is an interesting instance. There are two or three varieties of this disease, and in each case it comes from a microbe that enters the blood of man through the bite of a mosquito. The microbe

passes through various stages of development in the body of the mosquito, finally invading the salivary glands of that creature. A mosquito bite transfers these microbes to the blood of man, where they enter the red blood-cells and embark on a further stage of development. For some time they multiply within the blood-cells, then burst out of them, and invade fresh blood-cells. There then comes a quiescent stage, during which the microbes remain inactive within the blood-cells, and ultimately die. It may happen, however, that during this resting phase a mosquito bites the man and absorbs some of his blood. If the red cells so absorbed contain the malaria microbe it starts its process of development in the body of this new mosquito, and thus a new carrier of the disease is created. Malaria cannot pass directly from man to man, or from mosquito to mosquito. It has to pass from mosquito to man and from man to mosquito.

An even more complicated chain of connection is provided by the history of the liver fluke, the parasite that inhabits and devours the liver of sheep and other grazing animals. The eggs of these creatures are carried by the bile to the intestine of the sheep, and from these are excreted, and so reach the exterior world. In warm, moist weather these eggs hatch, and from them emerge minute organisms only one two-hundredth of an inch long. These are

very different from their parent fluke, which is about an inch long. This minute creature hunts about to find, if possible, a certain kind of snail. If it is unsuccessful it dies; if it is successful it bores its way into the body of the snail, and there grows and gives rise to a number of offspring. It then dies. These offspring are unlike their parent or the original fluke. They are small, worm-like creatures. They get their nourishment from the body of the living snail, and give rise to several generations very like themselves. By the time the cold weather comes a change occurs. Instead of the generations repeating themselves a new kind of creature appears with a large head and a small tail. These creatures bore their way out of the snail and establish themselves on wet blades of grass or other herbage. If now a browsing sheep or other grazing animal eats this herbage these creatures enter his liver, where they grow and produce eggs. Thus the cycle is complete, and the liver fluke starts over again. Our natural disgust at contemplating such creatures is almost overcome by our wonder at the amazing complexity of the rhythm of their lives. Such examples, even if multiplied a million-fold, would not exhaust the subtlety and variety of the forms and processes of life.

In the world of living things there are innumerable interconnections. The evolution and present

existence of any species cannot be understood by studying that species alone. The examples we have given are spectacular illustrations of this fact. Equally striking examples can be given where the relation is not of devourer and victim, or that of host and parasite, but one of mutual help. We have already mentioned the partnership between leguminous plants and certain kinds of bacteria. Here the plant fixes carbon, and the bacteria fix nitrogen, each benefiting the other. A large number of such instances of mutual help could be given, sometimes between plant and plant, sometimes between animal and animal, and sometimes between plant and animal.

We see that any region of nature, if left to itself, rapidly attains a state of equilibrium, a balance being reached and maintained between the various forms of life that inhabit it. It is true that there are occasional outbreaks of over-multiplication, but through disease or some other agency, the original balance is soon restored. The greatest disturbing influence on our planet is man. Wild nature is a remarkably stable concern. Nevertheless, as the theory of evolution makes clear, it is continually, but very slowly, undergoing change. On the time-scale of history this change is inappreciable. But on the geological time-scale change is seen to be the keynote of the world of living things. A tendency to

change, our modern theories tell us, is inherent in the living substance itself. Mutations are constantly occurring, caused we know not how. Whether these mutations, in any particular case, suffice to establish a new kind of creature upon earth, depends on the environment. We may suppose that for every mutation which is a success there are many that are failures. Every step has to justify itself. Sometimes it appears that no change has been necessary. There is a sea-creature—lingula—that has persisted unchanged from the earliest times. It lived and flourished in those incredibly remote early seas just as it lives and flourishes now. Apparently it is so perfectly adapted to its environment that no improvement upon it has occurred in hundreds of millions of years. But not all change seems to have been utilitarian. We have already said that it sometimes appears that a creature has gone on obstinately changing in a certain direction, although this persistence had brought no advantages with it, and may even have been positively disadvantageous, and that an instance seems to have been provided by the giant reptiles. As we have seen, these creatures dominated the earth for one hundred million years. And then, quite suddenly, they became extinct. They banked, as it were, on size and strength. They attained dimensions which put them beyond competition. And having attained this stage they went

on growing until they were immobilized, as it were, by their own tremendous bulk. They could no longer move fast enough to gather the food necessary to support them. Another instance of what seems to be the same sort of irresistible urge, although not attended with such fatal results, is provided by a group of fish related to the shark. These fish, probably because it was found useful, have developed in the direction of flattening bodies and thinning tails. But the development seems to have gone beyond any possible usefulness, and has become merely grotesque. The tail has become reduced to a mere lash. Other instances of this sort of purely automatic development can be given. It has been suggested that such developments are, in some cases at least, secondary effects. Although useless in themselves they are necessary accompaniments of the main, and useful, line of evolution that the creature is pursuing. Such phenomena introduce an element of disequilibrium into nature. But, on the whole, we may describe the slow and continuous change in the world of living things as being a progress from one state of equilibrium to another.

THE END

NAMES OF ELEMENTS

AND THEIR ATOMIC WEIGHTS ARRANGED IN ORDER OF THEIR ATOMIC NUMBERS

No.	Name.	Weight.	No.	Name.	Weight.
1.	Hydrogen	1·008	36.	Krypton	82·9
2.	Helium	4	37.	Rubidium	85·45
3.	Lithium	6·94	38.	Strontium	87·63
4.	Beryllium	9·1	39.	Yttrium	88·7
5.	Boron	10·9	40.	Zirconium	90·6
6.	Carbon	12	41.	Niobium	93·5
7.	Nitrogen	14·01	42.	Molybdenum	90
8.	Oxygen	16	43.	Masurium	—
9.	Fluorine	19	44.	Ruthenium	101·7
10.	Neon	20·2	45.	Rhodium	102·9
11.	Sodium	23	46.	Palladium	106·7
12.	Magnesium	24·3	47.	Silver	107·88
13.	Aluminium	27·1	48.	Cadmium	112·4
14.	Silicon	28·3	49.	Indium	114·8
15.	Phosphorus	31	50.	Tin	118·7
16.	Sulphur	32·06	51.	Antimony	120·1
17.	Chlorine	35·456	52.	Tellurium	127·5
18.	Argon	39·9	53.	Iodine	126·92
19.	Potassium	39·1	54.	Xenon	130·2
20.	Calcium	40·07	55.	Cæsium	132·8
21.	Scandium	44·5	56.	Barium	137·37
22.	Titanium	48·1	57.	Lanthanum	139
23.	Vanadium	51	58.	Cerium	140·2
24.	Chromium	52	59.	Praseodymium	140·6
25.	Manganese	55	60.	Neodymium	144·3
26.	Iron	55·8	61.	Illinium	—
27.	Cobalt	58·97	62.	Samarium	150·4
28.	Nickel	58·68	63.	Europium	152
29.	Copper	63·6	64.	Gadolinium	157·3
30.	Zinc	65·4	65.	Terbium	159·2
31.	Gallium	70·1	66.	Dysprosium	162·5
32.	Germanium	72·5	67.	Holmium	163·5
33.	Arsenic	74·96	68.	Erbium	167·7
34.	Selenium	79·2	69.	Thulium	168·5
35.	Bromine	79·9	70.	Ytterbium	172

No.	Name.	Weight.	No.	Name.	Weight.
71.	Lutecium	174	82.	Lead	207·2
72.	Hafnium	178·5	83.	Bismuth	208
73.	Tantalum	181	84.	Polonium	210
74.	Tungsten	184	85.	Unknown	—
75.	Rhenium	—	86.	Radon	222
76.	Osmium	191	87.	Unknown	—
77.	Iridium	193·1	88.	Radium	226·4
78.	Platinum	195	89.	Actinium	(226–227)
79.	Gold	197·2	90.	Thorium	232·1
80.	Mercury	200·5	91.	Protoactinium	231
81.	Thallium	204	92.	Uranium	238·5

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